HIGHWAY RESEARCH RECORD

| Number 408 | Transportation Planning for Natural Resource and Recreation Development |

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FOREWORD

The papers in this RECORD focus on the general problems of planning for resource management.

Rechel and Witherspoon state in their paper that the environmental problems of transport for development and utilization of natural resources are highly varied. The authors state that, within the scope of environmental problems themselves, standards have to be set and enforcements have to be effected. However, for such tasks there is a conspicuous deficiency of knowledge with respect to the incidence and extent of the specific environmental problems in developing countries, as well as the technological know-how to deal with them. The authors suggest research studies needed in the area of transportation related to natural resource development.

A series of papers follows that report on research at the Institute of Transportation and Traffic Engineering on techniques to perform transportation systems analysis within the framework of resource management planning for national forests. Sullivan, Layton, and Kanafani give an overview of the various analytical techniques (travel-demand models, network-analysis models, and procedures for data collection and management) tested for a proposed process for national forest planning.

Kanafani in his paper describes the design and conduct of a travel survey conducted at Tahoe National Forest in California. The paper is concerned mainly with the part of the survey dealing with recreational travel.

Sullivan describes a set of travel demand models developed to estimate recreation traffic on the transportation system of a national forest. These models were tested on travel pattern data collected at Tahoe National Forest.

Gyamfi documents the development of a model for allocating travel demand and the application of this model to allocate recreational demand from the centers of population in California to the national forests in California.

Layton in his paper describes the applications of network analysis for transportation for timber activity and administrative travel in national forests.

ENVIRONMENTAL ASPECTS OF TRANSPORT FOR NATURAL RESOURCE DEVELOPMENT

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The environmental problems of transport for natural resource development and utilization are highly varied, widespread, and far-reaching. Such problems include exhaust emissions; noise and vibration; waste disposal and other pollutions to land, water, and air; and hazards to human living. The precise dimensions of a particular environmental problem depend on the types of resource material to be moved, the natural conditions of the location, and the economic, social, and commercial circumstances of the nation or region, as well as the techniques and facilities of transportation to be used. To deal with the various problems, it is necessary to undertake appropriate transport planning for natural resource development and utilization from the point of view of environmental quality. This involves considerations of the economic and physical factors as well as, in each individual case, a balance between cost and benefits. Transport planning calls for the establishment of a suitable policy and a program of work with properly defined objectives and priorities. Within the scope of environmental problems themselves, standards have to be set and enforcements have to be effected. For such tasks, however, there is a conspicuous deficiency of knowledge with respect to the incidence and extent of the specific environmental problems and the technological know-how to deal with them in developing countries. Thus it is suggested that research studies be undertaken in the first instance in three areas: (a) surveys for defining the incidence and extent of known environmental problems arising from transportation for natural resource development in developing countries; (b) research into the unidentified areas of environmental implications of transport for resources purposes; and (c) research into the technologies and techniques for control of the environmental effects of transport for resource development.

●THIS paper attempts to review existing knowledge in the area of study, to identify those issues requiring the attention of policy-makers, and to suggest some of the possible solutions that are available or will be in the future. It points out emerging environmental issues and provides a framework within which these problems can be appreciated and dealt with.

Four major sections set forth the subject. The first delineates major relationships between transport and natural resource development. It identifies the nature of environmental effects, both direct and indirect, that can result from the various transport requirements for resource development. It discusses the differential impact of these effects, from first-order consequences (e.g., erosion from road construction) to second- and third-order consequences involving changes in land use and settlement patterns and size.

The next section details the effects on the environment of transport infrastructure and operations. Transport modes considered include roads and highways, railways, pipelines, conveyors, overhead cable systems, waterways, and airways.

The third section is devoted to the economic development and equity issues arising from a high degree of concern with the environment. Costs, and their distribution, are considered, as are the problems of dealing with existing environmental violations and taking preventive action.

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The final section highlights some of the major policy issues and future directions of effort. Alternate transport technologies to reduce environmental damage are also reviewed, and several priority areas for future research are suggested.

In this paper the analysis is focused on those environmental aspects of transport for natural resource development that are of particular interest to developing countries. It is worth noting, however, that the environmental concerns of developing and developed countries are different. The former are primarily concerned with resources in the sense of whether there are sufficient supplies of food, energy, materials, and so forth to meet their needs; the latter are increasingly concerned about the ability of air, land, and water to absorb all the wastes they generate.

RELATIONSHIPS BETWEEN TRANSPORT AND NATURAL RESOURCE DEVELOPMENT

The Environmental Effects: Direct and Indirect

The environmental effects that result from transport for natural resource development can be distinguished as to whether they are direct or indirect. As used in this paper direct effects are defined as those that take place in the immediate area of resource exploitation or in the transport way that provides access to it. (Although direct effects cover the full range of social, economic, and environmental impacts, in this paper we are primarily concerned with the environmental impacts.) For example, as a consequence of roads constructed to provide access to mineral deposits, thousands of acres of previously undeveloped land may fall prey to poor limbering practices, squatter settlements, strip burning, and so forth. Such direct effects are the primary concern of this paper. Before dealing with these, however, a brief digression on indirect effects is required.

The indirect effects of transport for natural resource development are those that occur in other areas of the country (or in the world) because of a change in access to a specific location. To continue the examples cited, uncontrolled timber cutting can reduce the economic viability of controlled timber cutting elsewhere; likewise, new cultivation of "free land" can compete destructively in some markets with existing cultivations in other locations. In arid countries where water is scarce, a new transport access may enable entrepreneurs to capture a new water resource with canals or pipes. The indirect effects can include drastic downstream consequences (e.g., seasonal water shortages) or long-term disadvantage (e.g., the dropping of stream standards below desirable water-quality levels).

Many indirect effects are subtle changes that are seldom of early and direct concern to the private entrepreneurs and public officials who are immediately involved in resource development. Nevertheless, indirect effects are noted here as being of potential concern to regional, national, or multinational planners. At the present time, most indirect effects are imperfectly understood or anticipated. Where they are identified, action can only be taken on a case-by-case basis. As more is learned about the indirect impacts—social, economic, and environmental—of seemingly separate problems, it may prove possible to identify in advance a broad range of indirect effects and to devise a long-range strategy for action. However, for the remainder of this paper the primary concern is with the direct environmental effects, i.e., those in the immediate area of resource development or in the transport way that provides access to it.

In discussing environmental effects, it is necessary to recognize the time frame within which the impacts occur. Direct effects may have an impact on the immediate environment almost at once or only after varying periods of time. Environmental effects that might have an immediate impact include those arising from transport into an area for access to and extraction of a primary material. Over longer periods of time, changes in land use or settlement patterns may result. And eventually an area's ecology can be altered basically. In these latter cases the processes of environmental change can be ones where the lead times are long but the momentum is strong and the process irreversible. It is extremely difficult for existing planning processes to deal with such long-range situations.

Transport Requirements for Resource Development

Direct effects on the environment will depend on the nature of transport requirements for resource development: the time frame during which transport demands arise; the direction of movement; the volume, type, and weight of materials that must be transported; and the settlement patterns that arise as a result of resource development. The diversity of these requirements in the real world, of course, is enormous; here it is possible only to distinguish the major possibilities and identify the various kinds of environmental effects that can be expected to result from each.

Time Frame for Development—Most resource development takes place in either of two quite different time frames. For such activities as the exploration for oil or the construction of dams, there is a temporary need to transport into a site a large volume of equipment and material. For resource development per se, the transport requirements in such cases rarely last more than 5 years. Following completion of the activity, the traffic to and from the site usually drops to a small fraction of its temporary total. For such activities as mineral extraction or lumbering, on the other hand, the need for heavy and sustained transport can extend over a period of 5 to 20 years or more.

The environmental implications of these two basically different time frames for resource development are important. Temporary transport needs are likely to be met with "least-cost" roads characterized by poor engineering, cheap construction practices, and little or no environmental planning. Such transport ways may not even provide a viable access for more than a few years after the close of the initial resource development activity. In contrast, long-term transport needs usually dictate better designed, more costly roads. Such roads are usually those with proper drainage and a good fit to contours of the land. In and of themselves they cause far less damage to the environment than does the other class of roads. Properly designed roads, however, are also available for access over long periods of time and are thus more likely to bring about long-term changes in land use and settlement patterns in the immediate area.

Direction of Movement and Volume, Type, and Weight of Materials To Be Moved—A second determinant of environmental effects is the direction of movement required by resource development and the volume, type, and weight of materials that must be transported. Taken together, these factors combine to determine the choice of transport way; for purposes here, however, it is useful to separate these factors for analysis.

The major consideration for direction of movement is in relation to the ruling grades, a particularly important factor in countries with hilly and mountainous terrain. If heavy weights are required to go downhill, overall road length can be shorter, with a somewhat closer fit to contours of the terrain. If heavy weights must go uphill, a longer road with larger cuts and fills is required. The latter, of course, carries with it a much more extensive environmental effect in terms of potential erosion, natural drainage, and so forth.

The volume of materials that must be moved determines in large measure the capacity requirements of transport ways and thus the potential environmental effect. To continue the example, if very large trucks must be able to pass each other easily in opposite directions at all points, the access road must be wider than otherwise would be the case. If volumes are sufficiently high, railway transport may be employed. However, because of the curve and grade restrictions on railways, the total length of the transport way will be longer than for roads, the cuts and fills larger, and the direct environmental effects more extensive.

The type and weight of materials to be moved can also have differing environmental effects by dictating the mode of transport that must be used. If, for instance, distances are more than a mile, timber must be hauled by truck. (Aerial cableways can be used for short distances, and recently there has been some experimentation with cable-guided balloons, but neither are cost-effective for distances of any consequence.) Large building stones are another example of a resource usually requiring truck transport, even for very short movements, as are most granulated or crushable materials. The latter two may be moved by conveyor systems or pipelines if the volumes to be moved are

sufficiently high. Both of these modes disturb the immediate environment less than roads or railways. But any means of continously flowing transport must have high volumes of materials to be moved if it is to be justified economically for distances of more than a few thousand meters.

Settlement Size and Patterns—A third determinant of environmental effect concerns the settlement size and pattern that may be required to carry out resource development. Any organized activity must draw direct labor and supporting services from somewhere. If the distances involved in resource development are small and a local labor supply is available, people may be moved by vehicles from existing communities to the site of activity and no new settlements will be directly required. Much resource development, however, requires additional manpower and supporting services to be brought into the area, in which case a new settlement must be established. For some forms of resource development (e.g., dam building) such settlements are temporary. In other cases significant settlements may be permanently established despite their lack of amenity and place in a plan (e.g., Brasilia).

Large settlements of 2,000 persons or more generally tend to have a significant and long-term effect on the immediate environment, especially in motorized countries. (Some small settlements may also have important impacts in certain cases—for example, by drawing upon limited water supply in arid areas.) Eventually, settlements may bring more access roads, air pollution from vehicles, and sewage and solid-waste disposal problems. Construction of cities requires that large land areas be cleared and leveled. In some countries this may mean draining wetlands and other natural habitat areas to remove birds, small mammals, and other wildlife. And ultimately as settlements grow, residential, commercial, and industrial activity will come, thus increasing the potential environmental effects manyfold.

Particularly in developing countries characterized by great urban population growth, it is difficult to overemphasize the importance of planning settlement patterns. Clearly, planning is critical for settlements that are intended to be permanent. Less obvious is the need to take into account the population potential of even temporary settlements. If new access for one resource (e.g., minerals) opens up other easily exploited resources (e.g., timber, arable land), a temporary settlement may grow much faster and become much larger (and hence more permanent) than originally intended; as a result, of course, the environmental effects are multiplied. Furthermore, these effects may be magnified by other factors. In many nations, large segments of the population are chronically in search of jobs, particularly employment in the monetary sector of the economy. The possibility of a job and the attractions of city life can cause large-scale rural migration to settled areas. The result takes the form of squatter settlements at the periphery of a population center—all too often on submarginal land without basic services. Since to provide services to these areas becomes more difficult and expensive once squatter settlements have been built, it is usually desirable to discourage settlement in submarginal areas or at least to channel squatters to more suitable sites. In such cases the eventual savings in providing public services may justify additional transport costs to secure a better long-term location for the settlement.

ENVIRONMENTAL EFFECTS OF TRANSPORT INFRASTRUCTURE AND OPERATION

Environmental Effects of Transport Infrastructure

Roads and Highways—In most countries, both developed and developing, the major form of transport for resource development is by road or highway. Probably the major immediate effect of these transport ways on the environment is erosion. Erosion is an obvious problem with cheaply built, low-capacity roads, typically used for first access to a resource development area. Such roads are often crudely cut with bulldozers and are not well graded and drained. Even where roads are paved, erosion is a major effect because of the destruction of ground cover and the opening of new drainage channels. Natural drainage may also be changed in minor ways, affecting areas immediately adjacent to the road. However, the limited construction involved in low-capacity roads usually precludes more extensive drainage effects, and in some cases natural drainage may even wash out a cheaply constructed road.

Erosion is a major environmental effect of many transport ways, and it merits a brief digression here. Many factors determine the extent of erosion from transport ways, including the kind of soil, the slope of the terrain, the intensity of rainfall, and the construction methods used. Much erosion occurs during the construction period (and depends on the type of way constructed, as discussed later).

Erosion can also occur after the construction period. For example, areas below a completed construction site may still erode because of runoff from impervious pavement, service areas, or compacted soil.

As this example suggests, erosion affects both the immediate construction site and beyond. Erosion damage to the construction site (what are here called direct environmental effects) can include gullied slopes and channels, washed-out work roads, undercut pavements and pipelines, and debris-laden work areas. This kind of damage can be repaired but always at considerable additional cost and with delays in work schedules. In addition, the indirect environmental effects of erosion can extend far beyond the immediate construction area affected.

Beyond the immediate environmental effects of roads on erosion and drainage, the most important impact of roads is on land use. As a consequence of roads, thousands of acres of previously undeveloped land may be opened for easy exploitation. Uncontrolled timber cutting is a frequent result. In addition to being an eyesore, uncontrolled timber cutting can also damage forests and their habitats, which support varied species of wildlife. The tendency to raise only one crop (monoculture) for the benefit of lumber and pulp can have environmentally significant effects, not the least of which is the loss of many native species. This in turn allows insects to flourish, insects that can devastate large forests of single species. Widespread application of insecticides is often necessary in the aftermath.

Transport access can also open up land for other abusive monocultures, often accompanied by strip settlements, razing of forests, and removal to new sites every 2 to 4 years. This in turn serves to destroy natural cover and accelerate erosion and the destruction of watersheds. In less forested areas, overgrazing can have dramatic environmental effects of a similar nature. Overgrazing occurs where cattle, sheep, and other livestock are overstocked on already depleted ranges. As a result the range's exposed soil is eroded away as wind, rain, and drought sweep over it. Particularly in arid and semiarid countries, the climate can add to the destruction.

As a result of new transport access, significant new settlements may arise, either because of population pressures pushing migrants to look for alternative settlement sites or because of resource development activity that encourages settling. In the long run, such land use changes and population concentrations are often the most significant environmental effect of new access roads.

Modern highways of a relatively high standard occasion some of the same environmental problems as cheaply built low-capacity roads but in different ways. The widths and gradient control of most well-designed, high-capacity highways require that large amounts of earth be moved in areas of rolling or mountainous terrain. This means that highway construction tends to create a greater erosion problem at the time of construction than do most cheaply constructed low-capacity roads. Such highway construction can increase the rate of land erosion a hundredfold (1, pp. 37-38). Once built, however, higher quality construction usually reduces erosion directly around the highway itself, although the major changes in runoff can create erosion in adjacent areas.

The impact of highways on natural drainage may be considerable, particularly where highways must be planned in the absence of adequate data. Unfortunately, good hydrographic studies are extremely expensive. This problem is pervasive and deserves some discussion because it affects not just road and highway construction but most major construction projects for transport ways.

In most developing countries, and particularly outside of major river basins, hydrographic data (e.g., on local rainfall, waterflow, drainage) simply do not exist. Moreover, such data are usually very expensive to accumulate. A preliminary study and description of drainage, for example, typically requires the presence of professional hydrographers over at least a 1-year period, along with extensive complex measurements and observations. An additional difficulty is that such preliminary studies still

cannot provide the historical measurements (e.g., the 10-year maximum 24-hour rain-fall) that may be the most important information to take into account. It is well known, for instance, that major construction fills often create "dam" effects that have unfore-seen consequences. A typical effect is that construction projects create dams across wet-season runoffs, which in turn can cause changes in water distribution and even-tually major flooding. In areas where historical data on local hydrography are available, highway or railway engineers can plan on the basis of such information. More typically, however, data are nonexistent, with the result that estimating stream flows and rainfall fluctuations is purely guesswork. Consequently, the environmental effects from such construction projects can turn out to be very harmful.

Another environmental effect of highways is that a high-standard road will usually bring with it a large volume of traffic, particularly if vehicles are available and a large urban area is near. Traffic resulting from tourism and recreation is but one case of additional land use that can have significant environmental effects if uncontrolled. Un-limited access to wilderness areas, for example, may transform such areas into simply another extension of civilization. Land-clearing and the destruction of flora and fauna on a fairly large scale typically accompany such traffic where there are no controls. For the long run, the tremendous boom in tourism in some countries (e.g., Mexico), teamed with rapid and cheap transport access to new areas, can threaten the very values on which tourist attraction is based.

Finally, it should be stressed that, as a general rule, the more money that is in-vested in the design and construction of a road, the less its immediate impact on the environment. Nevertheless, the pressure is almost always to build the greatest length of road or highway with any amount of money that is available. Problems of cost, therefore, are probably paramount in attempting to alleviate the environmental effects of highways and roads.

Railways—Generally speaking, the very high geometric standard to which railways are built and the requirement for easy curves and grades tend to cause much greater environmental effects as a result of construction than in the case of highways and roads. Railways also result in an even greater dislocation of natural drainage, due to the very large cuts and fills that open up relatively greater topsoil areas. On the other hand, railways are generally accompanied with less change in land use and settlement along the areas adjacent to the right-of-way than are highways and roads; the latter are easily accessible to people of little or no means but with substantial household effects to carry. Railroads are much less so.

With regard to the area of resource development activity, however, the very large transport capacity and relatively low cost of railroads may bring pressure for timber cutting or sand and gravel removal on a larger scale than would be the case for high-ways and roads. These are perfectly acceptable activities, of course, when carried out in the context of effective public controls to prevent poor practices. However, such supervision does not exist in many countries, regardless of their state of development.

Inland Waterways—Typically, the development of river basins for resource exploita-tion requires reliance as well on a number of supplementary transport ways. Because only a minority of river basins are navigable, most require access by road or rail of some kind. What is more, if waterways are expensive to bridge, transport is usually required on both sides of the basin, with feeder networks extending into the hinterland. For such supplementary transport ways the same environmental effects discussed earlier would apply.

Aside from these effects of supplementary transport systems, the use of inland waterways themselves for resource development can have important environmental implications. Particularly in countries with long coastlines and extensive river sys-tems, inland waterways may afford the easiest transport between widely dispersed inland areas. Inland waterways have long been the most important means of shipping agricultural products in some areas, and water transport can also maintain a position of some importance in mineral extraction (e.g., the large-scale iron-ore traffic on the Orinoco River system of Venezuela). Efforts aimed at improving inland waterways may range from the construction of canals to the dredging of deepwater channels in delta areas and along rivers themselves to permit direct access by oceangoing carriers. Full

discussion of the environmental effects of river basin development is beyond the scope of this paper. It should be stressed in passing, however, that dramatic changes can result when attempts are made to alter the course of nature by tampering with river ecosystems.

The St. Lawrence Seaway has contributed significantly to the economic growth of the Great Lakes Region in the United States and Canada by permitting inland access for oceangoing vessels. Nevertheless, it has done so at a high and largely unforeseen cost to the environment:

> The completion of the Welland Canal let the predatory sea lamprey into the Great Lakes. Trout, which had been the backbone of the Lakes' fishing industry, suffered greatly from the lamprey invasion. By the mid-1950's the trout and some other large, commercial predatory fish were nearly extinct. And with their near extinction, smaller fish, especially the alewife, normally kept under control by these predators, proliferated. The agressive alewife dominated the food supply and greatly reduced the numbers of small remaining native fish, such as the lake herring. The alewife became so numerous, in fact, that on occasion great numbers died and the dead fish along the shore caused a major public nuisance.
>
> Man attempted to restore the ecological balance by instituting sea lamprey control in the 1950's and 1960's and by stocking the lakes with coho salmon beginning in 1965—to replace the lost native predatory fish. Feeding on the abundant alewife, the salmon multiplied rapidly and by 1969 had become important both as a commercial and sport resource. Some of the salmon, however, were contaminated by excessive concentrations of DDT and were taken off the commercial market (1, p. 7).

The lesson from such examples, of course, is not that large-scale attempts to develop river basins should be abandoned but that the consequences of developing major river basin projects should be carefully studied from an environmental point of view in advance of undertaking the project.

Pipelines—The major environmental effect of most pipelines is in their construction, which usually cuts a swath through ground cover. In arid or semiarid areas with a flat terrain and relatively little natural growth, the construction of a pipeline usually carries with it little effect on the environment. Likewise, pipelines normally do not cause uncontrolled exploitation of resources in adjacent areas, because there is no paving or metalling over the right-of-way.

Perhaps the most publicized environmental effect of pipelines is when, depending on the commodity and location involved, pipelines must carry heated materials. Even though pipelines are insulated, there will be some effect on the surroundings. The seriousness of such environmental effects depends on the diversity (and hence the stability) of the particular ecosystem affected. A complex tropical forest, for example, provides more ecological stability than the limited plant and animal life found on the Arctic tundra. In the latter case the introduction of instability—conceivably by a heated pipeline—could trigger frequent violent fluctuations in some animal populations such as caribou, lemmings, and foxes.

Generally speaking (and aside from the problem of oil pollution discussed later), one can conclude that, from the standpoint of their environmental effects, pipelines can be preferred to most other forms of transport ways. Concern for the environment would suggest, therefore, that more emphasis be placed on the development of slurry transmission at lower daily tonnages as a possible substitute for road or rail transport of excavated materials.

Conveyors—Of all the high-volume material movement systems, conveyors probably disturb the environment least. Conveyor systems are usually built on a series of concrete or masonry piers and hence cause less damage to the immediate environment than pipeline construction. The range of possible applications for conveyor systems is limited, however, because, if costs are to be competitive, large volumes of materials must be moved.

Overhead Cable Systems—Of all movement systems, overhead cables usually have the least environmental impact. Unlike conveyor systems, cableways usually have long spans between piers and thus do not require the construction of heavy components at relatively short intervals. The cost of movement for overhead cable systems,

however, is relatively high, for both construction and operation. Moreover, capacities are limited compared to conveyors or pipelines. At the present time, therefore, over-head cable systems are used only for relatively short distances (usually under 2,000 meters) in conditions of sharp slopes and severe terrain.

Air Transport—The environmental effects of air transport facilities will depend in large measure on anticipated and actual volumes of traffic. For most resource development transport (as distinguished from passenger and cargo services), the traffic generated will be limited due to the restricted carrying capabilities and relatively high costs. In some areas, however, air transport may develop and hold a considerable advantage. One example is that of meat shipment in countries such as Venezuela that are heavily dependent on this product. In Venezuela, several companies specialize in airlifting freshly killed steer carcasses to urban markets from points in the llanos not served by roads. Large-scale ranchers selling in Caracas and Maracaibo find the relatively high freight charges well compensated for by avoiding losses that would have been incurred by driving their animals on the hoof.

Where the volume of anticipated traffic requires air transport facilities to handle airplanes substantially larger than DC-3's, this usually implies a major construction project. Typically, a bulldozed road must be cut to the construction site in order to move equipment in and out. (One can build a 3,000-ft strip for airplanes under 30,000-lb gross weight by flying in equipment by air; beyond this, however, such a process becomes extremely expensive.) Thus, for building airports of any significant size, a major construction project is involved, much in the manner of the mining or dam-building projects discussed earlier. The environmental effects of these efforts would also apply with regard to providing access for the construction of air transport facilities.

Environmental Effects of Transport Operations

Exhaust Emissions—Obviously, the operation of machines on highways and roads—particularly trucks and automobiles—creates some air pollution. Air pollution adversely affects man and his environment in many ways with regard to human health, to vegetation and materials, to visibility, and to climate. However, the environmental effects of exhaust emissions are probably not significant in most transport operations for resource development, since these do not normally involve high traffic volumes and air pollution of objectionable intensity. Therefore, transport operations for resource development generally do not cause significant air pollution, except insofar as settlements are encouraged and large cities eventually grow up. Exhaust emission concentrations are, however, extremely objectionable and costly in city street networks.

Noise and Vibration—Transport operations for resource development can also generate noise and vibration. Aside from the normal noise and vibration for air and surface transport, the major problems are likely to arise in the exploitation processes themselves, especially in mining and crushing. In areas subject to landslides or snow avalanches, however, even normal noise levels caused by heavy vehicles of any kind (including trains) are hazardous. Preventive action to alleviate this problem would thus entail a necessary additional cost.

Temperature Changes—Changes in temperatures would seem significant only with regard to pipelines, as previously mentioned, and then only in relatively few cases. As indicated, heated pipelines would be objectionable in Arctic regions because of the effect on local ecology. In tropical countries, however, there would not appear to be any marked effect, as witness the movement of palm oil by pipeline in Malaysia. Neither would a properly insulated refrigerated line, which in most cases would be short in length anyway.

Oil Pollution—Oil pollution can result from the operations of various transport modes, many of which are not peculiar to resource development. Certainly the most dramatic of examples are the large oil spills (those exceeding 100 barrels), most of which come from oceangoing carriers operating outside of inland waterways. Nevertheless, a particularly significant source of pollution in some harbors and river basins occurs when ships discharge bilge and ballast water heavy with oils and other substances.

Oil pollution can also spring from sources on land. The disposal of millions of gallons per year of used motor-vehicle (crankcase) and industrial lubricating oils can pose a severe pollution problem. Principal disposal methods are dumping in sewers and rivers, dumping on land, use as road oil or for agricultural purposes, incineration, and reprocessing to fuel or lubricating soils.

In addition, oil (and other) pollution can result from hundreds of thousands of miles of pipelines, with daily capacities in the millions of barrels, that cross land, waterways, and reservoirs. Such pollution (in addition to the effects of pipelines on local ecosystems, as discussed earlier) can come both along the line and at terminus points. Construction and operation of such pipelines may create oil pollution along the line, either through chronic low-level leakage or through major breaks. Contamination of the water supply can be among the most damaging environmental effects. For example, if pipelines are laid in areas with extensive underground aquifers used as sources of drinking water or as catchments, there is a potential danger of serious water pollution. Because pipelines are often laid in trenches, it is frequently difficult to detect the point of leakage, and pollution may become apparent only miles away from its source. Where pipelines are above the ground, leaks and breakage can occur from faulty construction of foundations.

For most pipeline systems, the primary potential for oil pollution occurs at pipeline terminal points, where oil spills can be associated with the terminus itself or with storage loadings, de-ballasting, and shipping disasters. Oil spills can have damaging effects on marine life at the terminus (and consequently on the livelihood of local fishermen) as well as affecting water quality, as indicated above.

Prevention of oil pollution calls for careful planning of pipeline location, sound construction practices, and regular inspections of pipeline systems, particularly at terminus points. Contingency plans should be developed for cleaning up any oil spills, and tanker traffic should be controlled with the assistance of the latest navigational and communication systems. The dumping of oily ballast water in port areas should also be prohibited.

Waste Disposal—Waste disposal as a result of transport for resource development would appear to be a problem only in the case of slurry pipelines where water used to prepare the slurry may be wholly or partly drained off. Conceivably, the local pollution problem created could become serious if this water were dumped directly into a stream. On the other hand, if the water were put through settling ponds, the accumulation of residue over the years might be considerable. This suggests that interface terminals for the removal of water from slurry pipelines be placed away from peopled settlements. (In some applications, such as coal movement, this may not be necessary because the water is not removed.)

Routings—As transport networks grow, there may be cases where alternate routings for heavy motor vehicles from mineral- or timber-producing areas would enable these vehicles to be detoured away from areas of recreational appeal. The desirability of alternative routings would arise both to enhance the enjoyment of tourists and to preserve wilderness areas from ecological damage.

Settlement Implications—Another aspect of routing that merits separate attention concerns settlement implications. As indicated, the mere existence of regular transport of any kind has the tendency to encourage settlements unless local conditions are very forbidding. If settlements are undesirable in areas adjacent to access ways, controls of some sort will be necessary. Concern with settlement implications also suggests that resource access roads avoid routings too close to existing settlements. If it becomes necessary in exploiting a resource to recruit local labor, a connecting road for buses may be built. But construction and heavy hauling traffic should be kept away from settlements.

Processing Plant Locations—A great many materials—most notably mineral ores of any kind—place a premium on processing near the point of extraction in order to reduce the amount of unusable material that must be transported long distances. Processing plants require transport on their own account, and they produce waste (sometimes in very large volumes) that can have considerable effects on environment. In some cases the location of a processing plant so as to minimize transport costs could have drastic

effects on the environment. This would be particularly true where plant locations are close to population concentrations. Concern with the environment would suggest that the consequences of processing plant location be studied carefully from an environmental point of view in advance of undertaking the project. In some cases higher costs may have to be accepted if the potential environmental effects appear particularly damaging.

ECONOMIC DEVELOPMENT AND EQUITY ISSUES ARISING FROM
A HIGH DEGREE OF CONCERN FOR THE ENVIRONMENT

Increased Transport Costs

The Effects of Increased Costs—Any improvements over existing transport practices for resource development will require additional costs. Transport costs are essentially of two kinds: one-time outlays (for providing transport infrastructure) and continuous outlays (for providing transport operation over time). The environmental effects of transport infrastructure and operation, as well as the kinds of improvements that could be made, have been discussed in the foregoing. In this section the concern is with the economic development and equity issues that arise as a result of increased transport costs.

The effects of increased transport costs on resource development enterprises will be determined generally by the principle of marginal costs. Simply stated, each increment in costs (over and above "existing" conditions, either actual or estimated) in the delivered price of a primary resource (or products produced therefrom) will make the resource more expensive relative to similar resources from other locations. (The quantity of the product that can be sold at the new price, of course, will depend on the elasticity of demand, discussed later.) To illustrate this principle in practice, two examples may be distinguished: that of the monopoly supplier and that of the multiple supplier.

In the first situation, a resource is extracted by a single supplier, often for consumption in the originating country. In such cases there is the possibility of controlling exploitation of the resource or the prices charged. If there are no controls, the elasticity of the product's demand will determine its market following an increase in transport costs for protection of the environment. (If there are multiple suppliers under oligopolistic conditions, there will most likely be a differential increase in transport costs. If environmental protection is required in one producing area but not another, the higher cost area will be at a competitive disadvantage. This will at least restrict the marketing radius of the high-cost production area and may even render prohibitively expensive the continued exploitation of resources there.)

In the second situation, there are many suppliers, and presumably the resource is traded in world markets. The possibilities of price and marketing controls when goods are traded in highly competitive markets are considerably reduced. The increment in transport costs will tend to limit the radius of marketability and may dictate whether the resource material can be developed profitably at all.

The extent of increased transport costs (and thus the effects on resource development) will be closely related to the degree of environmental protection desired. In general, the stiffer the standards applied, the higher the additional transport costs are likely to be.

The Distribution of Increased Costs—The increased costs for transport that arise as a result of concern for the environment may be borne by producers, consumers, the general public, or some combination thereof. As a general matter it can be assumed that producers will attempt to pass on any increased costs to the consumer. If a product is locally consumed and the demand for it is inelastic, then the consumption of the product will be largely maintained, at least in the short run. In the more likely event that the demand for a product is elastic, then less of the product will be purchased at its higher price. Governments may be called on to relieve this situation through various subsidies, price controls, and other measures.

If a product is traded internationally, then the shifting of additional costs to the foreign consumer will depend on the strength of the product's market, its relative

price sensitivity for a given production area, and possible changes in the costs (and prices) of other producers. International policies of environmental protection might come into play here, and variations as to local meteorology, terrain, and drainage would be among the determinants of relative market prices, as discussed later.

It should be pointed out that many products, especially those with high unit values and small volumes (e.g., tin and chrome concentrates) have a high profit margin. Consequently, suppliers of these products who are faced with additional costs as a result of environmental standards may still stay in the market but at a lower level of profit. At least in the private sector, the more marginal firms will always be the first to be closed in times of increased market slack. (Public sector enterprises are probably more likely to get government subsidies for environmental protection, particularly where the establishments provide significant employment and/or contribute importantly to foreign-exchange earnings.) For products with low profit margins, with many sources of supply, and with sales in large volumes (e.g., bauxite, wheat) the economic viability can be vitally affected by very small increases in costs.

The Possibility of Internationally Distributed Costs—The costs of applying environmental protection standards seem certain to vary considerably from country to country. As a result, if standards are applied uniformly, then the differential increases in cost would certainly change the market relationships of both existing and prospective producers. Therefore, some form of international equalization may be deemed desirable. One approach might be an international aggreement on environmental protection standards modeled after the General Agreement on Tariffs and Trade (GATT), which has set forth principles of fair trading practices and has also led to a reduction in tariffs and other trade barriers. As applied to environmental protection standards, this approach could be accomplished in a manner that would keep most of the higher cost producers in the market at the expense of part of the profits of the low-cost producers. To some extent this would be a form of cross-subsidy from consumers—i.e., paying higher than necessary prices in order to obtain the largest and most widespread array of producers and at the same time a greater degree of environmental protection. The economic effect, of course, would be to spread the high costs of the most serious environmental preservation cases over the whole of the world market. If such an arrangement were not possible, then the enforcement of environmental standards would have exactly the same effect as any other cost element in the delivered price. As a result of increased costs, some production would not be initiated, some marginal existing operations would be forced to close down, and the rest would become less profitable.

Dealing With Existing Violations—If environmental standards are applied to new facilities only—and not to existing operations—then their major effect would be to discourage the establishment of certain new economic activity. New resource exploitation would be undertaken at a slower rate. However, the retroactive application of standards—that is, to both new and existing operations—poses an additional dilemma, i.e., the problem of existing violations.

The application of standards may mean substantial investments in nonproductive equipment and operations, interruptions in production, reductions in labor force and share of the market, and, conceivably, relocation to another country or shutting down altogether. Noncompliance with standards, on the other hand, implies a continuation of damages to the environment as well as the possible risk of international retaliation (e.g., through trade restriction).

Where existing violations are from operations that provide significant employment or contribute substantially to foreign-exchange earnings, the dilemma is particularly difficult. The fact that private enterprise may bear part of the compliance costs does not basically alter this public-policy consideration. In countries attempting to achieve sustained economic growth, the use of resources from either the public or the private sector for environmental protection is probably unproductive in the short and medium term. This assumes, of course, that most benefits to be derived from environmental protection are long run in nature (i.e., 15 to 20 years) and are therefore difficult to justify on a discounted cash flow basis over shorter periods of time.

If standards are applied, it is difficult to avoid the conclusion that governments would eventually pay for at least part of the cost of compliance in a majority of cases. If large investments are involved, however, it seems unlikely that many governments, particularly those in developing countries, can be reasonably expected to act. Action is especially unlikely on the part of those governments that believe they are already in an unfavorable competitive position.

Measuring Relative Cost Burdens

If in the long run some international financial assistance is to be made available for hardship cases, or if enforcement variances are to be granted, some means of measuring the relative cost burdens between nations in each case will be required. Among the factors that would be considered are the following:

1. The relative costs of environmental protection;
2. The relative wealth of the country (per capita GDP or some similar index could be used);
3. The relative fiscal capability of the country and the way this capability is used;
4. The extent to which environmental protection costs can be covered by the private sector;
5. The extent to which costs are in foreign exchange (particularly significant where up-to-date capital equipment must be installed); and
6. Some type of "optimum opening year test" on major portions of the larger outlays.

It may be desirable to include other factors, of course, and these are listed only to suggest some of the more important possibilities.

Distributing Relative Cost-Burden Assistance

If international assistance were available for hardship cases as a result of environmental protection controls, such assistance would clearly not cover all the control costs for all applicants. This raises the problem of how much assistance should be distributed. Among the factors that could be considered are the following:

1. The incremental costs of environmental protection compared with the incremental benefits that are expected to result from controls;
2. The overall project cost in relation to general measures of government activity (e.g., GDP, total government budget, capital budget, public works budget);
3. The relative foreign-exchange content and current foreign-exchange position of the country;
4. The public finance capability and relative "extent of effort"; and
5. The relationship of the case in question with regional, multinational, or international plans and problems.

Again, this list is illustrative, not necessarily complete.

MAJOR POLICY ISSUES AND FUTURE DIRECTIONS OF EFFORT

Identifying Problems, Priorities, and Objectives

The Appropriate Policy Context—Environmental problems are large and diffuse, and their true nature may be masked in many ways. As a result, policy-makers are not faced with a given problem (or even a set of problems) but a number of discrete environmental effects (e.g., erosion from road construction, abusive monoculture that arises as a result of new access ways). How these problems are dealt with will depend on how problems are defined. This, in turn, will be determined by the context in which policy-makers consider the environment. How a policy problem is perceived, how it is classified (either consciously or unconsciously) for purposes of analysis and action, and what group of policies it is related to are all part of the policy context.

Among the issues that might be considered in this connection are the following: Does it make sense to talk about the environment as a whole? Or must one deal with a series of specific problems? Should the focus be on the medium through which effects occur

(e.g., air, water), on particular kinds of pollutants (e.g., oil, solid waste), or on the immediate location where effects are felt (e.g., land adjacent to transport ways)? Would a program of environmental protection be different from existing approaches (e.g., natural resource management), or is the environment simply a new way of looking at old things? The context in which environmental concerns are considered will determine (and be partially determined by) what standards are set, what enforcement policies are planned, and what levels of government and administrative agencies are assigned the tasks.

The Priorities—Perhaps the most important question facing policy-makers with respect to the environment concerns which problems to consider. The number of environmental problems is enormous; the time, money, and manpower available to deal with them are limited. Given the value differences and variations among areas, setting priorities is bound to be difficult. It is made even more so by the limited state of current knowledge. Nevertheless, an order of priorities has to be made, and an efficient program for solution of the problems has to be designed.

In light of this, what environmental problems resulting from transport for resource development are most pressing for an individual country? On what basis should priorities be set? The short-term benefits compared with the cost of taking action? The rate at which problems are increasing in intensity over the next few years? The irreversibility of long-term damage if immediate action is not taken?

The Objectives—Once problems are defined and priorities established, there are many specific environmental objectives that can be defined. One approach might begin with an objective stated in qualitative, nonnumerical terms (e.g., water suitable for swimming). This could then be translated into specific numerical quality levels to be applied to the environment (e.g., no more than X parts of suspended solids are to be allowed in river Y). Implicit in this approach is the notion that environmental protection is not an end in itself but a means to other societal values, such as health, recreation, aesthetics, and economic growth.

Thus, in this example, the objective of environmental protection is purely recreational. In this case investments in environmental protection should logically be compared with alternative investments for other kinds of recreational opportunities— e.g., the construction of swimming pools near centers of population. In the real world, of course, the objectives of environmental protection are likely to be much more complicated. But the important point is that policy-makers faced with decisions about the environment must weigh the costs and benefits of environmental protection against other societal goals—e.g., economic development. They must decide not just whether environmental protection is desirable, but how much should be spent to control what kinds of environmental effects, and where.

Standard Setting and Enforcement

The Standards—Assuming some agreement on the foregoing, policy-makers should be concerned with the two crucial steps in any program of environmental control: standard setting and enforcement. In the first, standards are set that prescribe what controls should be imposed or what action should be taken. In addition to stating the operational objectives of the program, such standards also provide a benchmark on the basis of which it is possible to measure progress.

Presumably, standards could be based on those environmental quality levels that are deemed desirable. To continue the previous example, a standard might state that no industrial plant could discharge effluent containing more than X parts of suspended solids into river Y. Such standards would represent the "teeth" of any control program.

Assuming that the desired environmental quality levels were not stipulated, another approach would be to tie standards not to some environmental objective but to prevailing "good practice"—e.g., installation of the best available control device or use of the best safeguard procedures possible. Particularly in developing countries dealing with the environmental effects discussed in this paper, the latter would probably be the only standard-setting procedure possible. Standards of this sort might stipulate that certain studies be made of the immediate environment prior to initiating major transport

projects or that specified design characteristics be incorporated at the time of construction. This implies that there is some public body to determine what good prevailing practices are, to see that such practices are adhered to, and possibly to provide incentives to encourage improvements in existing practices.

Whatever approach is taken to standard setting, a number of questions must be resolved. Should standards take into account the differences in marginal costs and benefits of environmental protection among various areas? Or should they be stipulated "across the board" for everyone? What account, if any, should be taken of variations in meteorological and hydrographic conditions, topography and terrain, and local ecology? In the event that the least-cost (including cost to the environment) transport route would traverse two or more areas, what should be proposed? Should standards be set ex post facto or retroactively?

The Enforcement—As used here, enforcement is the process whereby damaging environmental effects are halted or reduced and/or potential environmental effects are prevented. Presumably, enforcement would proceed on the basis of the standards set. But the step from standards to enforcement is by no means automatic. Consequently, a number of issues similar to those involved in standard setting arise, if in slightly different form.

An initial set of questions concerns how far enforcement should be extended. Should enforcement extend to all areas, or only those that can afford the burden of control costs (including reduced economic activity, if applicable)? To all areas affected by transport for resource development? Or only to those that appear to be experiencing significant environmental effects at this time? To all existing and future transport infrastructure and operation, or just to those in effect after enforcement begins?

A related set of questions concerns how swiftly enforcement should proceed. If ex post facto enforcement is required, should this be given first priority? Or should such improvements be implemented gradually over an extended period, as priority is accorded to the enforcement of standards for all new transport facilities? Should some areas—i.e., those with greater burdens—be given longer periods than others to reach full compliance?

A third set of questions concerns the economic development and equity issues discussed earlier. What variances, if any, should be granted to hardship cases? Should assistance of some sort be provided to help cover the costs of control? If so, who would pay for such assistance, and how would it be administered?

Areas for Enforcement—Environmental protection provides some excellent examples of problems that defy political boundaries. The appropriate area for dealing with water pollution, for example, is generally assumed to be the river basin. But most rivers cross jurisdictional boundaries of some sort, and many are in fact the dividing line between countries. This is perhaps less a problem with man-made transport facilities, largely due to the lack of cooperation among nations on regional airports, roads, and port facilities.

Nevertheless, a decision that must be faced in any environmental protection program concerns the logical geographic area for planning and implementing enforcement programs. Should it be the area(s) served by the transport way or the land immediately adjacent to it? Or should the area for enforcement be the region in which resource development occurs? Should the area of enforcement for the environmental effects discussed in this paper be one that coincides with the one for dealing with related environmental problems (e.g., water pollution)? In large measure, the appropriate area for enforcement may be determined by how the problem is defined (a transport problem, a water pollution problem, a resource management problem, etc.).

Another set of questions concerns the difficulty of striking a balance between the appropriate area for dealing with the problem (however defined) and the administrative agencies capable of dealing with it. Where the area of enforcement does not coincide with existing jurisdictions, what new kinds of legal authority and administrative machinery are needed? Where existing agencies are available, what are their capabilities?

Alternate Transport Technologies—Although alternate transport technologies probably offer little to relieve the existing environmental effects of transport infrastructure

and operations, they may open up some medium- to long-term opportunities. The following are illustrative of these possibilities.

Where transport access is required only temporarily and where extreme weights are not involved, airlifts, particularly by helicopter, may be used to lessen environmental effects. Oil-drilling operations offer an excellent opportunity of such an application. The use of airlift could also be applied to the laying of pipelines and conveyor systems. This would eliminate much of the bulldozer damage to ground cover and resulting erosion that was discussed earlier in detail. It may also be possible to airlift some seasonal crops, especially high-value perishable commodities like meat and fruit.

Another possibility would be the use of all-terrain vehicles with large tires and very low unit ground pressures. In many cases their use would require only the removal of trees, with the result that the typical environmental effects of road-building (e.g., ground damage, erosion) would be reduced. Not the least of the problems that could be alleviated by the use of ATV's are the long-term changes in land use and settlement patterns that are often occasioned by the opening up of new access roads. Access by ATV's would provide not nearly so attractive a transport way for settlement migrations. At present, however, ATV's have higher purchase prices and unit operating costs than conventional road vehicles. Another drawback is that, although ATV's can be obtained with high load-carrying capacities, they are presently rather slow, and thus the distances over which they can be used are limited.

Areas for Future Research—Three major areas of research are suggested as a result of this review of existing knowledge in the area of study covered here. First, much more needs to be known about the extent and seriousness of the problems that have been identified. Poor limbering practices may be cited as an excellent example. The prevalence of this problem is not entirely known, although it is suspected to be very widespread. Furthermore, there are likely to be built more access roads with serious environmental effects for log and lumber production than for most other major tropical products. (Pineapples, cane sugar, palm oil, and rubber are examples of commodities that are presently produced for the most part in well-established areas to which access roads have already been constructed.) With total world demand for sawlogs and timber growing faster than total world population, poor lumbering practices are likely to be an increasingly serious problem. Already some islands in the South Pacific have been denuded of timber in the process. But the worldwide prevalence of this problem is not known. If this were seen as a priority area, presumably some sort of global survey would have to be initiated before an environmental program could be begun. Other equally relevant examples could also be cited.

The second major area of research is concerned with the nature and extent of environmental effects. Much environmental research has been done along these lines in recent years. Yet, as this paper points out, much more needs to be known if problems are to be defined and enforcement programs developed. At the present time, roads are constructed and dams built with exceedingly imperfect knowledge as to their environmental effects on water, soil, fish, and wildlife. Concern for the environment would suggest more attention at the design stage of major transport projects to the environmental implications of construction, as well as the possibility of incorporating environmental safeguards into the basic design of new projects. It also suggests that more basic research and monitoring of the environment are needed. For example, the lack of basic hydrographic data for many regions of the world has been discussed earlier as a major problem facing planners engaged in resource development projects. Until more is known about the environmental consequences of alternative actions, it will be extremely difficult to determine what controls or safeguards should be imposed and how stringent they should be. The problem is particularly difficult because some environmental changes have long lead times, and their consequences do not turn up until many years later. Without better basic knowledge and information (What are the significant trends and changes? What are the important interrelationships? What do these mean to man?) one can only react to environmental effects after they have become serious enough to see. And unless some changes can be anticipated in advance, their consequences can be extremely costly and difficult (indeed impossible) to correct.

The third area of environmental research is concerned with methods of controlling the effects discussed in this paper. More needs to be known about effective and economical control techniques (e.g., practical ways of preventing erosion from transport ways). More also needs to be known about alternate transport technologies that are (or could be made) available to reduce environmental effects. The desirability of doing something about the environment depends in part on what can be accomplished and at what cost. More research in this area would go far in assisting policy-makers to determine what should be done.

ACKNOWLEDGMENT

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TRANSPORTATION ANALYSIS TECHNIQUES
FOR NATIONAL FOREST PLANNING

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During the past 3 years a major research program at ITTE has developed
an extensive package of techniques to perform transportation systems anal-
ysis within the framework of resource management planning for national
forests. These techniques include travel-demand models, network-analysis
models, and procedures for data collection and management. Two inter-
acting sets of travel-demand models were developed to analyze recreation
trip-making to national forests. The "macro-allocation" models estimate
aggregate statewide recreation traffic volumes to every national forest.
The "micro-allocation" models estimate the traffic volumes on the trans-
portation system of one particular study forest. Network-analysis models
were developed to analyze the efficiency of a forest transportation system
for low-volume nonrecreation traffic. This paper describes the role of
these analytical techniques in a proposed process for national forest plan-
ning. Each of these models and supporting techniques is described, and
their interactions are discussed.

•PLANNING for resource management in a national forest is performed by a group of
Forest Service personnel representing the professional disciplines involved in its
management. The members of the multidisciplinary group and the responsible decision-
maker pool their diverse skills to create a single comprehensive plan that includes mu-
tually consistent directions for all aspects of forest operations. The formal sequence
of activities that is followed to develop a forest management plan is called the "resource
management planning process."

The purpose of this paper is to present an overview description of a package of ana-
lytical techniques that have been developed to aid in this planning process. Because
many of the techniques involve mathematical abstractions of the physical world, they
are called "models." Although one could perform a planning process without models,
and, indeed, much planning is performed that way, the size and complexity of the forest
system is such that analytical models are desirable.

The planning models presented are designed primarily to facilitate the analysis of
forest transportation system alternatives. However, because transportation is not an
end in itself but supports other activities such as timber harvest, recreation, and fire
protection, transportation analysis models must relate to these other activities and be
useful for their analyses. Performing joint analyses of diverse forest activities is
essential to producing a comprehensive plan.

THE STRUCTURE OF THE PLANNING PROCESS

Figure 1 shows the major components of the resource mangement planning process.
This process is an application of the "systems approach," which is a problem-solving
method unsurpassed in objectivity and orderliness. The arrows in the figure represent
interdependencies among the various components. The broken arrows represent spe-
cial interdependencies called "feedback loops," which allow the process to cycle re-
peatedly through its various components until an acceptable plan is obtained.

The first component of the planning process is the definition of explicit goals and
objectives. Goals and objectives are the driving force of the process, because, until

one defines an end toward which to work, there is no need for a plan. The goals and objectives are necessarily explicit in order to resolve, at the outset, any differences that may exist among the planning group members. Fortunately for the national forest planning process, this agreement among participants is more readily achievable than in the analogous urban and regional planning situations.

The second component of the process begins once the planning objectives are established. The planners determine exactly what should be known about the probable effects of any plan in order to evaluate it effectively. The measurements that represent these effects are called "measures of effectiveness." Because the adoption of a measure of effectiveness is controlled by the availability of acceptable analytical methods to determine its value, the selection of analytical techniques is performed at the same time. Given the requirements of typical national forest planning process, the selection of analytical techniques would include some and possibly all of those described in this paper.

The third component of the process is the definition of alternatives. Several significantly different courses of action are identified for each aspect of forest operations, and these are then combined in realistic ways to create a number of alternative comprehensive plans.

If there is one lesson to be learned from the large metropolitan area transportation planning studies, it is with respect to the collection of planning data, the fourth process component. It is essential that sufficient information be accumulated to provide an understanding of the situation being studied. However, collection of data must always be related closely to subsequent use. Only enough data must be collected to meet the identified needs of the planning process, plus any well-defined needs in administrative or public relations areas.

The fifth component of the planning process is the analysis of alternatives. "Analysis" is estimating the measures of effectiveness, that is, the consequences, of every alternative plan. Planning models, as well as other quantitative and qualitative techniques, are used to obtain these estimates.

The sixth component is the evaluation of alternatives. "Evaluation" means pulling together the products of analysis into a form that facilitates convenient and meaningful comparision of the alternatives. Consequences involving monetary costs and benefits at different points in time are made comparable by discounting techniques. Voluminous data describing the qualitative and quantitative consequences of every alternative at many different locations are distilled to their essentials and meaningfully displayed. The effects of different implementation schedules for each alternative are considered, and the sensitivities of the various consequences to scheduling and to other factors are determined.

The final component of the process is the selection of a plan. Typically, the accumulated evidence suggests the consideration of a plan different from any of the alternatives that were studied. If these differences are minor, their implications are generally determined by returning to either analysis or evaluation. If the differences are greater, a new formal alternative may be defined. The process continues to cycle in this way until an acceptable final plan is obtained.

The plan developed through this process is used thereafter as an evolving guide to decision-making. Because no plan can fully anticipate the future, as time passes the plan is modified to account for increased knowledge and changing policies. At periodic intervals, reviews and occasionally complete revisions of the plan are performed within the formal framework of the planning process.

ANALYTICAL TECHNIQUES IN THE PLANNING PROCESS

The analytical techniques introduced in this paper are used within the planning process to analyze transportation and its interaction with other forest activities. The techniques described may not all be applicable in each forest. In each case the techniques that are suited to the character of the forest activities are used. For example, if a study forest is far from large population centers and has little recreational use, the recreational models may be deemphasized or possibly eliminated from the planning

process. This package of techniques is therefore seen not as a fixed sequence of steps for analyzing a particular problem but as a toolbox from which planners can draw whatever capabilities are appropriate to the analyses to be performed.

Two principal groups of models have been developed: those that are used to estimate the recreational traffic on forest transportation networks, called "recreational travel models," and those that are used to determine the efficiencies of forest transportation networks for other types of traffic, called "nonrecreational travel models." These two groups are described in the following sections.

RECREATION TRAVEL MODELS

It was decided that the most useful measures for evaluating the impact of recreational activities on a national forest transportation system are estimates of the recreational traffic associated with the alternative plans. Consequently recreational travel demand models were developed to estimate the probable traffic volumes under alternative sets of future conditions. These conditions include:

1. The locations and characteristics of forest resources and recreational areas;
2. The characteristics of the forest transportation network;
3. The locations and characteristics of population centers within a reasonable journey time to the forest;
4. The characteristics of the regional transportation system that links the population centers to the forest;
5. The locations and characteristics of "competing" recreation complexes in the region; and
6. Information about the travel behavior of recreationists.

Recreational traffic estimation is treated as a two-stage problem. First, there is the problem of how many visitors will be attracted to the forest from surrounding population centers. Second, there is the problem of how these visitors, once they are there, will disperse to the many recreation areas located therein. Related to the latter is the additional problem of how people who are staying overnight in the forest, such as campers, will travel about during their stay. To deal with the two-stage nature of the problem, two distinct but interacting groups of recreational travel-demand models were developed. There are the "macro-allocation" models, which estimate aggregate travel demand from population centers to the forest, and there are the "micro-allocation" models, which estimate traffic on the forest's roads and to its recreation areas.

The two groups of recreational travel models have analogous properties. Both groups contain "generation" models and "distribution" models and use a common "attraction model.". The "generation" models estimate the number of recreational trips that will occur. The "distribution" models predict their destinations. And the "attraction model" computes the relative inherent drawing power of forest resources and developed facilities. The interrelationships among these models are shown in Figure 2.

The specific characteristics of the attraction model and of the models in the macro-allocation and micro-allocation groups are discussed in the following paragraphs.

The Attraction Model

The attraction model (5, chapter 7) is not really a travel-demand model. It is concerned not with traffic estimation per se but rather with the characteristics of the areas that attract the traffic. The technique is almost identical to that employed in an Ontario recreation study by Ellis (8). It employs factor analysis to reduce the many variables describing facilities and natural resources to a few representative factors. For a given area, the factor loadings—that is, the relative weights of the facilities and resources present—are combined to yield a single measure that fairly represents that area's relative wealth in the various characteristics assumed to determine inherent attractiveness. These measures are used to represent the characteristics of destinations in both macro- and micro-allocation. The attraction model can be used to estimate both the relative attractiveness of competing areas within a study forest and the relative attractiveness of an entire study forest relative to all competing recreation complexes.

Figure 1. The resource management planning process.

DEFINITION OF GOALS AND OBJECTIVES

DETERMINATION OF THE INFORMATION REQUIRED AND SELECTION OF ANALYTICAL TECHNIQUES

DEFINITION OF ALTERNATIVE PLANS

COLLECTION, MANIPULATION, AND PRELIMINARY ANALYSIS OF DATA

ANALYSIS OF ALTERNATIVES

EVALUATION OF ALTERNATIVES

PLAN SELECTION
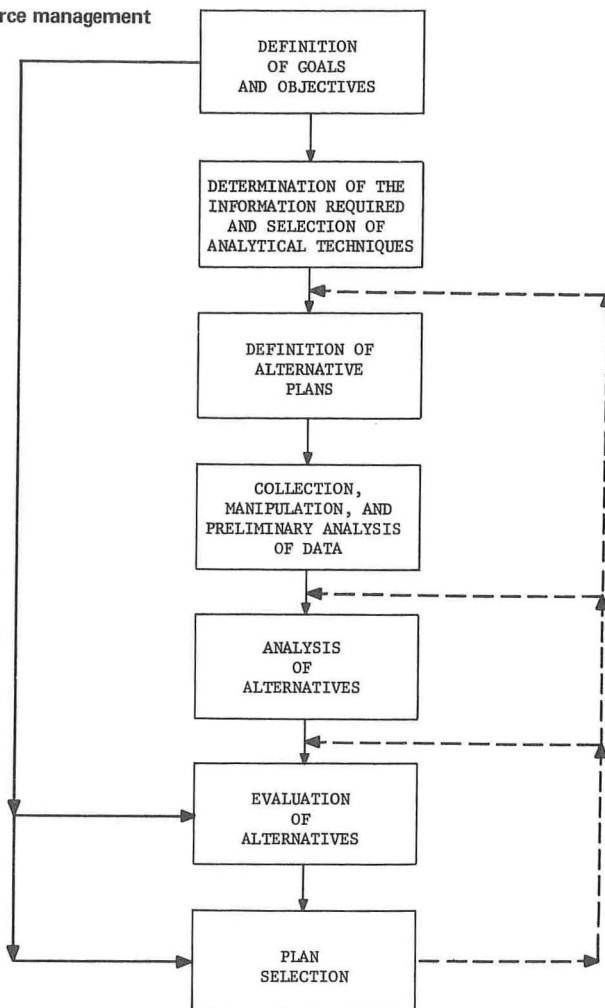
Figure 2. The national forest recreational travel-demand models.

population centers

MACRO-GENERATION MODEL

MACRO-DISTRIBUTION MODEL

MACRO-ATTRACTION MODEL

MICRO-GENERATION MODEL

MICRO-DISTRIBUTION MODEL

MICRO-ATTRACTION MODEL

recreation facilities

forest   forest   forest
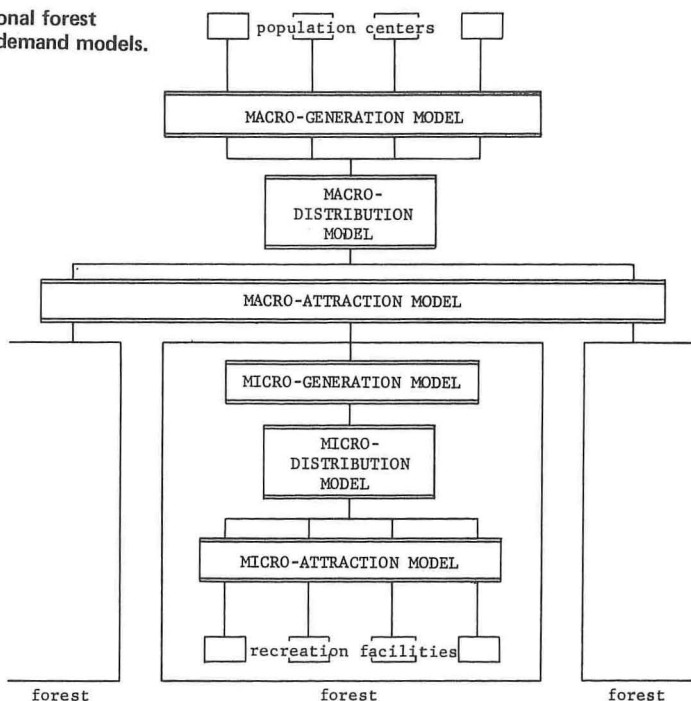
The Macro-Allocation Models

The macro-allocation models estimate the aggregate numbers of recreationists who will visit a forest from outside the immediate forest area. The macro models do not consider visits from nearby residents since these can be estimated more accurately by micro-allocation procedures. The models are designed to make estimates from whatever data are available describing the attributes of the study forest and the competing recreation complexes.

The macro-generation model estimates the aggregate demand at each population center for recreational travel to the study forest and to the competing recreation complexes. This demand is based on the demographic characteristics of the center. Because it is infeasible to send data collection teams out to the various population centers to measure recreational trip-generation rates directly, these quantities are estimated by employing the macro-distribution model backward in order to determine the population center trip-end volumes that would explain the pattern of forest visits observed in a forest recreation travel survey (5, chapter 8). These estimated trip-end volumes are then used to fit a traditional type of regression model to population center demographic variables.

The macro-distribution model (2) considers the aggregate demand at the population centers, the cost of travel over the regional transportation system, and the relative attractiveness of the study forest and all competing recreation complexes to determine the probable number of trips that will be made to the study forest. It is a systems model, such as that used in previous work by Ellis (8), and is analogous to methods for computing flow quantities in electrical and other physical systems.

The macro-allocation models are general enough to estimate recreational travel to any set of competing recreation complexes, which may include either national forests alone or national forests plus state and national parks and major private facilities. Of course, the more competing complexes that are brought into the analysis, the greater the data needs. The planning team determines which types of competition are important influences on the aggregate recreational demand in their forest and then defines the scope of the macro-allocation analysis accordingly.

The outputs of the macro-allocation models are estimates of total trips for aggregate trip purposes, such as "single-day visits" and "overnight visits." The aggregate purposes are consistent with the level of detail of the available data. Following macro-allocation analysis, these estimates are disaggregated to equivalent estimates for specific recreational trip purposes and used as inputs to the more detailed micro-allocation analyses.

The Micro-Allocation Models

The purpose of the micro-allocation models is to estimate the volumes of trips attracted to individual forest recreation areas and to determine the corresponding traffic volumes on the local transportation network (3). The use of disaggregate trip purposes—for example, camping, lake fishing, and hiking—is necessitated by the widely varying characteristics evident in different kinds of recreational travel.

In terms of the two-stage traffic estimation problem, the macro-allocation models can be seen as playing the role of a micro-generation model. The micro-distribution models treat trips to the forest from the outside population centers as if they were generated at known nearby locations called "gates." This mechanism eliminates the need to represent components of vastly different scale, such as campgrounds and metropolitan areas, in the same model.

Seperate micro-generation models exist to estimate the numbers of trips originating at forest area overnight accommodations, such as campgrounds, motels, and cabins (5, chapter 10). These models are trip-making rates stratified by trip purpose, trip-maker characteristics, and characteristics of the locations where the trips originate. The structure of these models is based on the experiences and lessons learned in trip-generation analyses performed in urban and regional studies.

The task of micro-distribution—that is, determining where the generated trips will go—requires a range of models to deal with the diverse travel characteristics of

different trip patterns and purposes. Currently, there are three distribution models developed for the planning process:

1. The "impedance-dependent opportunity model" is an intervening opportunities model modified to be sensitive to the increment of travel impedance incurred in by-passing destinations (3, 6). The model is therefore sensitive to two measures of spatial orientation: opportunities intercepted and impedance overcome. The technique is suited to estimating trip patterns where the attracting recreation areas are well defined and substitutable and where travelers are reluctant to travel farther than they need to satisfy their trip purposes. Examples of trips in this category are swimming and fishing trips and most camping trips.

2. The "simple proportional model" is essentially an extension of the attraction model (3, 6). It distributes a total number of trips among recreation areas in pro-portion to their inherent relative attractiveness. This model is used where the attrac-ting areas are well defined and substitutable and where the relative distances to be traveled have little effect on the traveler's choice. Examples of trips in this category are camping trips to a limited number of highly developed campgrounds.

3. The "touring travel model" is a linear programming formulation that directly estimates network flows for trips having destinations that are not well defined and for which travel difficulty is a relatively minor consideration (7). The model operates by attempting to satisfy a priori estimates of relative link popularity, subject to con-straints on trip-end volumes at origins, the average trip length, and conservation of network flows. Examples of trip types for which this model is suited are sightseeing, hiking, and trail bike riding trips.

NONRECREATIONAL TRAVEL MODELS

There are two approaches that might be taken in developing models to analyze non-recreational travel. The first is to develop travel-demand models that estimate the volume of nonrecreational travel in a manner similar to the recreational-travel models. The second is to develop models that determine the efficiency of alternative plans for nonrecreational travel, given likely levels of traffic. The models that were developed for the national forest planning process are of the second type. They are called "network-analysis models."

Network-analysis models were chosen to analyze nonrecreational travel for two reasons. First, indicators of transportation network efficiency with respect to non-recreational travel are more relevant for decision-making than estimates of the rela-tively small traffic volumes that are characteristic of nonrecreational travel. Second, nonrecreational traffic is usually so sporadic that there is little hope of finding the statistical regularities required to construct a reliable demand model.

Two nonrecreational travel models have been developed (4). They are useful for analyzing transportation network efficiency for timber harvest travel and for forest administrative travel. A brief description of each follows.

The Timber Transport Model

The timber transport model is a technique that computes the shortest routes for hauling timber from cutting locations to railheads via mills. Three different routes can be determined, based on minimizing travel distance, travel time, and travel cost. The projected cuts at every location are then combined with the measures of route efficiency to compute an overall measure of timber transport efficiency for a given alternative resource management plan.

In addition to its role in planning, the timber transport model is useful for analyzing the efficiency of day-to-day timber operations. Theoretically, operators can be com-pelled by contract to move their cuts along the most efficient routes, thereby maxi-mizing revenues for both themselves and the Forest Service.

The Forest Administrative Travel Model

The forest administrative travel model employs an integer programming algorithm to compute the most efficient routes and schedules for meeting the regular service requirements in a national forest. The model determines the least-cost solution, subject to a maximum workday length constraint. Except for the requirement that the personnel must begin and end each working day at a single dispatch point, this model is the same as the classical "traveling salesman" problem (9). There is currently a significant limitation on the size of the network that can be analyzed, and work to expand the model's capability is continuing.

As in the case of the timber transport model, the forest administrative travel model is useful for analyzing the efficiency of day-to-day operations.

DATA REQUIREMENTS FOR ANALYSIS

This section briefly describes the data needs of the planning models. Although a large data base is required, efficient techniques of data collection and data management can be employed to reduce data costs. The roles of survey design procedures and data management systems are also discussed in this section.

The data described here do not represent the total needs of the resource management planning process. They are only the needs of the planning models described in this paper. The other components of the process, especially evaluation and definition of alternatives, have their own data needs, but these are not considered here.

There are two general types of data required by the models: inventory data and activity data.

Inventory Data Requirements

Inventory data represent what is known about the physical system under consideration. Although the planning process is concerned generally with a single national forest, there is need to collect less detailed information about the portions of the outside world that interact significantly with the forest.

Because the planning models are oriented to the analysis of the forest transportation system, it is natural that an inventory of that system be required. Because of the level of detail at which many of the models operate, it is necessary to have data on all relevant sections of forest roads and trails as well as information on other permanent transportation links, such as ferry boats and aerial logging systems. In general, the location, length, and service characteristics of each link are required. For macro-level recreational travel estimation, an inventory of the regional transportation system is also required. The regional transportation system would, of course, be inventoried in considerably less detail than that of the national forest.

The second major class of inventory data describes the resources and facilities in the forest. A major subset of these data is the inventory of recreation area characteristics required by the attraction model. This need is met largely by the "resource inventory management system," a facilities-inventory scheme used in national forests. The principal need is for study forest data, but the macro-allocation models also require some data describing the resources and facilities of competing recreation complexes. Other inventory data, such as the locations and characteristics of timber stands, mills, high fire-danger areas, and assignments of personnel, are required for the various nonrecreational travel models.

Another class of inventory data describes the locations and characteristics of the population centers that interact with the study forest by generating recreational travel. This demographic information is all available from publications of the U.S. Bureau of the Census.

Activity Data Requirements

Activity data describe the type, amount, and nature of the use made of the physical system. The principal use of activity data is in the calibration and testing of the recreational travel-demand models. In addition, information on timber-cutting activities is

employed by the timber transport model. Other less extensive activity data are required by the administrative travel model.

The principal activity data requirement of the recreation models is information on the use of forest resources and facilities. For a given forest, this information can be obtained both by direct measurement, such as by counting traffic entering and leaving facilities, and by asking visitors to itemize their use of forest facilities. Both sources of information contribute to the needs of the models. Head and axle counts gathered regularly in all national forests provide the aggregate use data needed to calibrate and test the macro-allocation models. Interviews with recreationists, expanded by means of traffic counts, provide the detailed use information needed to calibrate and test the micro-allocation models (1).

The Roles of Survey Design and Data Management Systems

Techniques of survey design and systematized data management are employed to reduce significantly the costs of using sophisticated planning models. In fact, without such techniques, it would be almost impossible to do all that must be done within reasonable budgetary constraints.

Survey design consists of applying probability theory to deciding how many data should be collected, when, and where. When such techniques are not used, there is a natural tendency to collect too much data and in such a way that many of them are redundant. Among the techniques of survey design, there are schemes for sampling at different locations in time and space so that most data requirements can be fulfilled economically. The techniques of survey design are especially applicable to the task of counting traffic and of conducting interviews with recreationists (1).

Data management systems are formal frameworks that control the collection, storage, editing, basic manipulation, and retrieval of data. In the case of large masses of data, these systems are generally computerized. When developing a data management system, one faces a dilemma in whether to have a very flexible system, which can handle many forms of data with variable efficiency, or to have a task-specific system, which can handle one form of data very efficiently. There is no pat answer, for the correct balance between flexibility and efficiency must be determined individually for every situation. Data management systems have been developed to facilitate the collection and use of the data required by the planning models. The characteristics of these systems reflect attempts to face at all times the question of balance between flexibility and efficiency.

SUMMARY AND CONCLUSION

The package of planning models and supporting techniques introduced in this paper is used by a multidisciplinary planning group to answer pertinent questions about the consequences of alternative forest plans. To a great extent, the various models are independent of one another, thereby permitting the various parts of the package to be used in the manner that best fits the planning requirements of a given forest. The supporting survey design procedures and data management systems also are modular in design.

These developments represent a significant addition to the set of capabilities available to those who must plan in order to meet the increasing demands of society on our fixed supply of undeveloped land. However, the package should not be considered finalized. A package of this type should always be subject to a process of growth and updating. Even as these techniques are being used in planning processes, work will be under way to monitor the degree to which the analytical needs of the processes are being met. Appropriate changes will be made to improve both the accuracy and the convenience of existing techniques and to introduce new analytical techniques as different planning issues become relevant.

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NATIONAL FOREST TRAVEL SURVEY

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This paper describes the design and conduct of a travel survey undertaken during the summer of 1970 at Tahoe National Forest in California. The survey was part of a research effort aimed at the development of transportation analysis techniques for national forest planning. This paper is concerned mainly with the part of the survey dealing with recreational travel, because in Tahoe National Forest it was observed that the most predominant use, and consequently most travel, was recreation-oriented.

•IN THE development of transportation analysis techniques a data base is essential. This data base contains information that aids in the understanding of the forest transportation and land use system and that is used in the construction and testing of analytic models of the system. The data base also contains information that can be of use in performing various planning and management activities. The two main types of information included in the data base are inventory data and activity data. The first includes a complete description of the land uses and transportation facilities present in the study area. These data are obtained mainly from available sources. The second type of information includes a description of the land use and transportation activities that take place in the study area. The acquisition of this type of data was the major purpose of the travel survey described here.

SURVEY FRAMEWORK

The Study Area

Tahoe National Forest is one of 18 national forests in California. It is located in the eastern part of central California northwest of Lake Tahoe in the Sierra Nevada. Tahoe National Forest covers an area of approximately 1,600 square miles and ranges in elevation from about 1,000 ft to over 10,000 ft.

Tahoe National Forest is a popular recreation area serving California and Nevada. The Forest has many rivers and lakes and includes a large number of camping and other recreational facilities. In 1969 the Forest attracted about 2.8 million recreational trips, of which slightly over 90 percent originated in California.

Apart from its recreational land uses Tahoe National Forest has a number of other uses. Foremost among these are timber logging and grazing. Figure 1 shows the transportation system and recreational areas of Tahoe National Forest.

Information Required

As mentioned previously, there are basically two types of data required for the development of transportation analysis techniques: inventory data and activity data. The purpose of the travel survey was to collect activity data. These data include two kinds of information: travel pattern information and land use activity information. Since most nonrecreational land use and travel pattern information could be obtained from available sources, the travel survey was mainly oriented toward recreational travel.

The travel pattern activity information for recreationists in Tahoe National Forest required the following items:

1. City of residence. This information is necessary for performing traffic-generation analysis in estimating travel demand to national forests in California.

2. Destination of main trip into the Forest. This information is necessary for the construction of allocation models that describe the distribution of travel demand among the various destinations within the Forest.

3. Modal and temporal characteristics. This information is needed to describe, for the purposes of possible model stratifications, the types of vehicles used by travelers to the Forest and the time patterns of their trip-making.

4. Travel activities within the Forest. This includes a complete log of all trips taken within the Forest on a day during the recreationist's stay. The log includes origin and destination, trip purpose, type of vehicle used, and possibly the route chosen for each trip.

The land use activity information that was obtained from the travel survey included the following items:

1. Main recreational activity. This information includes the main recreational purpose for visiting the Forest as well as other principal recreational activities undertaken by the recreationist during the stay in the Forest. It is a main stratifier of forest travelers (e.g., campers, fishermen, hunters) and is used for structuring models that describe the attraction of the various recreation sites within the Forest.

2. Frequency of Forest visits and durations of stays. This provides information about the use of the Forest by recreationists. It also provides information about the propensities for Forest visits generated by the various population centers in the region.

Apart from the travel activity and the land use activity information, it was necessary to obtain some descriptive information about the travelers themselves. This information, mainly socioeconomic, provides a basis for structuring models that describe the demand for recreation in the National Forests generated by various socioeconomic groups. The information includes the following items:

1. Traveling party characteristics (a traveling party was defined as any group of people traveling together in one or more vehicles): An indication as to whether the traveling party was a family, an organized group (e.g., scouts), or otherwise.

2. Traveling party composition: A description of the size of traveling party and of its age and sex distribution.

3. Traveling party income. For most traveling parties this was an indication of the annual income of the traveling household.

Survey Method

Three methods were considered for use in the national forest travel survey. These methods were compared, and an assessment was made concerning their suitability for use in the national forest setting. This section describes these three methods.

The first method considered was a card survey. Here the forest users would be handed pre-addressed questionnaire cards. The users would fill in the questionnaires and mail the cards back. This method is particularly suited for urban travel surveys because it is possible to sample addresses and send the cards to a sample of urban residents. In a national forest, however, it would be necessary to physically sample forest users on the roadside or at selected recreational sites in order to hand them the cards. Thus, in a national forest this method loses its main advantage of low manpower need. Another disadvantage of this method as applied in the forest is the effect of nonresponse. In an interview survey nonresponse can be identified and dealt with as the survey progresses, whereas in a card survey nonresponse can only be estimated and accounted for in advance of sending out the mail cards. In most locations within Tahoe National Forest it was found that the number of users (e.g., traffic on a particular road) was so low it was believed that errors in estimating nonresponse would be quite harmful to the validity of the remaining samples.

For these reasons it was felt that a card survey method was not suitable for a travel survey in Tahoe National Forest.

The second method considered for the travel survey was a roadside interview. This method involved interviewing travelers on their way out of the Forest at a selected number of roadside stations located at or near the Forest boundary. The travelers would

be interviewed by trained interviewers and asked about their transportation and land use activities while in the Forest.

This method appeared to have a number of advantages that made it quite suitable for application in the national forest travel survey. All of the required information can be obtained through one interview, and the survey forms can be completed by the interviewers themselves. This minimizes the possibilities of invalid responses or missing information. The roadside interview method also allows the use of a sampling technique that is flexible with respect to traffic conditions. Should a road be heavily traveled, then a smaller sampling rate can be used, thus causing less delay to traffic. Alternatively, if the traffic is very light, then a higher sampling rate can be used. Furthermore, this method permits identification of the incidence of nonresponse and the immediate adjustment of sampling to deal with it. The disadvantage that this survey method has is its high manpower requirement, because it is necessary to place interviewers at a number of different locations around the Forest boundary. Large traveling distances are involved for the interviewers, and equipment costs are high.

Another survey method that was considered was an interview survey conducted at a selected number of campgrounds and other recreation sites. This method has many of the advantages of the roadside interview method, but it also has a number of disadvantages. First, it involves interviewing recreationists while they are still in the midst of their stay in the Forest, thus requiring them to estimate their activities during the remaining part of their stay. This increases the amount of uncertainty of the information obtained. Second, it causes an interruption in the recreationist's participation in his activities, which for some type of activities (fishing, hunting, etc.) might not be desirable. Third, it requires dispersing interviewers over a wide area in the Forest in order to cover a representative sample of the recreation sites. This has a much larger manpower requirement compared with the roadside interview method, where all Forest users can be intercepted at a small number of stations.

Based on the evaluation described, it was decided that the method most suited to the national forest travel survey would be the roadside interview. However, in order to provide a certain degree of redundancy, it was decided to supplement the roadside interviews with a small sample of interviews carried out at a selected number of campgrounds. The information obtained from the campground interviews would be used to corroborate that obtained from the roadside interviews.

DESIGN OF ROADSIDE INTERVIEW SURVEY

The roadside interview involved selecting a sample of travelers leaving the Forest and interviewing them regarding the travel and land use activities that they undertook. The interviewing was supplemented by continuous traffic counts at the locations of the interview stations. The purpose of these counts was to provide information about the total population of travelers at these locations. This information was later used to expand the samples. The design of the roadside interview survey included three major activities: the choice of survey locations, the choice of survey dates and times, and the determination of sample sizes and sampling rates. In performing these three activities there were two guiding objectives. First, it was important to ensure unbiased samples. This meant that grographical bias had to be avoided in the choice of survey locations and that time biases and seasonal biases had to be avoided in the choice of survey dates and daily schedules. Second, it was important to ensure the statistical validity of the conclusions drawn on the basis of the samples. This meant that sample sizes and sampling rates had to be determined according to statistical methods.

Choice of Survey Locations

Seven locations were chosen for roadside interview stations. These locations are shown on the map of Figure 1. This choice of locations was governed by the need to have a sufficiently small number of stations to maintain reasonable survey costs while at the same time ensuring that the stations are an unbiased representative sample of the types of roads leading out of the major areas of the Forest. The stations were selected to be well-dispersed geographically over the Forest area and to cover a range

of road types. Two stations were located on a state highway that runs through the Forest (Highway 49). One of these stations (No. 1) was located in the western part of the Forest at a location with a relatively high traffic volume, and the other (No. 3) was located in the northern part of the Forest at a location with relatively low traffic volume. Two stations were located on major Forest roads leading to a major recreational area in the central part of the Forest. One (No. 2) was in the eastern part of the Forest, and another (No. 4) was in the southern central part of the Forest. Both roads have gravel surfaces. Two other stations were located on hard-surfaced roads; one (No. 5) was located in the central part of the Forest in an area close to a number of small towns, and the other (No. 6) was located in the southern part of the Forest where a recreational area is almost completely isolated from the rest of the Forest by a mountain barrier. Finally, a station (No. 7) was located on a minor Forest road with low traffic volume. This road is located in the central part of the Forest and is not surfaced.

Choice of Survey Days

In the choice of a period for the conduct of the survey, June 15 through September 15 was considered sufficient as a representation of the 1970 summer season. This choice was based on the fact that most Forest use occurs within this 3-month period. The period covered a total of 93 days, of which 66 were weekdays (Monday-Friday), 25 were weekend days (Saturday, Sunday), and 2 were major holidays (July 4, September 7).

Obviously it would have been excessively costly and unnecessary to conduct roadside interviews on all 93 days during the survey period. A sample was to be drawn. In doing this, 3 time variations in traffic and Forest use had to be accounted for to avoid any possible biases:

1. Weekly variations—variation in traffic characteristics among days of the week;
2. Monthly variations—variation in traffic characteristics among weeks of the month; and
3. Seasonal variations—variations in traffic characteristics among the 3 different months of the summer.

Of course a survey schedule that accounts completely for all 3 variations and all their interactions will be a complete schedule where all 93 days become survey days. This schedule is called a complete block design. If it is possible to assume away some of the interactions among these factors, then it becomes possible to reduce the number of survey days and schedule the survey as an incomplete block design. As an example of such interactions, we consider the interaction between weekly variations and monthly variations. By assuming this interaction to be negligible, it is implied that the difference between the traffic characteristics of a Monday and a Friday, say, is the same whether they are at the beginning or the end of the month.

By assuming that the interactions mentioned are negligible, it was possible to construct a block of 21 days in which each day of the week appears only once during each month of the survey period and in which the days of the week in each month are spread over the weeks of that month. Figure 2 shows this basic incomplete block design. The diagram is in the form of a calendar in which the numbers indicate the dates on which survey dates will fall.

The next step in the design of the survey schedule was to combine the basic incomplete block design for the 7 survey locations. Instead of conducting the roadside interview survey simultaneously at all 7 locations on each of the days shown in Figure 2, it was possible to replicate the same design on different days for different survey locations. This caused a great reduction in manpower requirements. The replication was done by shifting the design of Figure 2 by 1-day increments. To illustrate this combination we consider the schedule in Figure 2. Assuming that this schedule applies to the survey dates for interview station No. 1, it is possible to derive a data schedule for another station, No. 2, by scheduling this a day later. This pattern is shown in Figure 3. It can be seen there that on some days, particularly the weekends, duplication will occur in that both stations will be surveyed on the same day.
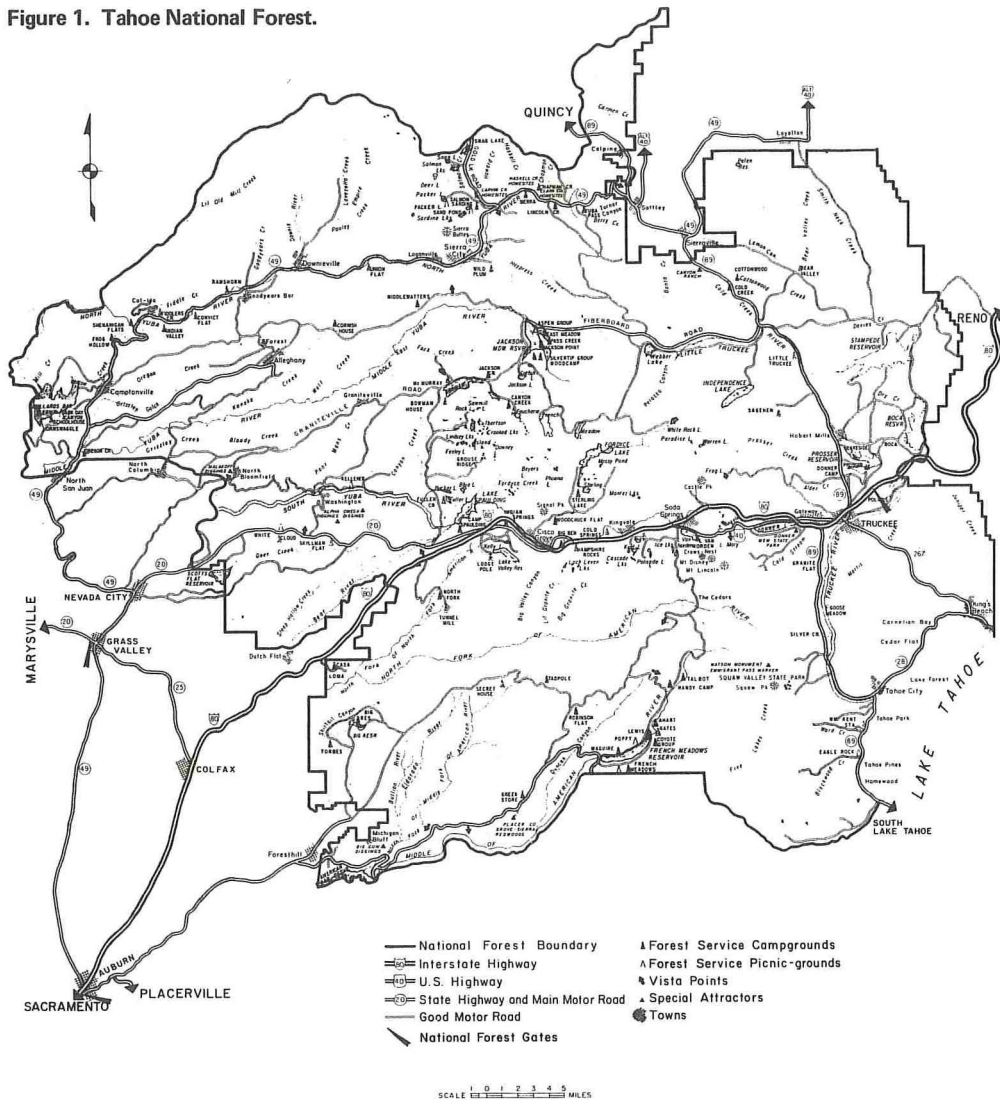
Figure 1. Tahoe National Forest.

National Forest Boundary	▲	Forest Service Campgrounds
Interstate Highway	∧	Forest Service Picnic-grounds
U.S. Highway	⚲	Vista Points
State Highway and Main Motor Road	▲	Special Attractors
Good Motor Road	🌳	Towns
National Forest Gates		

SCALE 1 0 1 2 3 4 5 MILES

Figure 2. Basic block design for survey days.

JUNE

S	M	T	W	Th	F	S
			17			
				25		

JULY

S	M	T	W	Th	F	S
					3	4
5	6					
		14				
			22			
				30		

AUGUST

S	M	T	W	Th	F	S
					7	8
9	10					
		18				
			26			

SEPTEMBER

S	M	T	W	Th	F	S
				3	4	5
6	7					
		15				

Figure 3. Block design for 2 survey stations.

1970	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
June 14				1	2		
June 21					1	2	
June 28						1	1 & 2
July 5	1 & 2	1 & 2	2				
July 12				1	2		
July 19					1	2	
July 26						2	
August 2	2	2		2			
August 9	1	1		2			
August 16				1	2		
August 23					1	2	
August 30					1	1 & 2	1 & 2
Sept 6	1 & 2	1 & 2	2				
Sept 13			1				

Figure 4. Roadside interview survey schedule.

1970	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
June 14						4 & 5	5 & 6
June 21	6 & 7	1 & 7			2 & 3	2 & 3	3 & 4
June 28	4 & 5	5 & 6					All
July 5	All	All	1 & 7				
July 12					5 & 6	1 & 7	1 & 2
July 19	2 & 3	3 & 4				5 & 6	6 & 7
July 26	1 & 7	1 & 2	3 & 4				
August 2							
August 9					1 & 2	3 & 4	4 & 5
August 16	5 & 6	6 & 7				1 & 2	3 & 2
August 23	3 & 4	4 & 5					
August 30					6 & 7		All
Sept 6	All	All	4 & 5			6 & 7	
Sept 13	1 & 7	1 & 2	2 & 3				

Table 1. Sampling framework for roadside interviews.

Station	Approx. 1-Way ADT	Approx. Percent Recreation	Approx. Recreation ADT	Sample Size by Criterion 1	Sample Size by Criterion 2	Sampling Rate
1. Highway 49 north of San Juan	500	30	150	369	200	3/4
2. Fiberboard Road at Highway 89	100	80	80	92	56	1/1
3. Highway 49 east of Yuba Pass	100	60	60	94	63	1/1
4. Bowman Road north of Highway 20	75	90	67	67	45	1/1
5. Washington Road near Highway 20	100	80	80	92	56	1/1
6. FH 96 east of Forest Hill	75	60	40	72	52	1/1
7. 19 N 14 south of Columbia Hill	40	90	36	37	29	1/1

To accommodate all 7 survey locations with the basic design of Figure 2, it was necessary that the design be modified so that on each survey day 2 stations were surveyed simultaneously. The choice of stations that would thus be surveyed was made on the basis of their geographic location, the objective being to minimize the amount of travel to and from the Forest as well as within it. Further reduction in manpower requirements was attained by considering only 5 types of days of the week instead of 7. This was done by considering Tuesdays, Wednesdays, and Thursdays to be equivalent days of the week. This modification did not reduce the comprehensiveness of the survey because it was observed that no significant differences occurred between the traffic characteristics of these 3 days.

The basic block design was further modified in constructing the survey schedule. On holiday weekends (Labor Day and Independence Day), the design was preempted and all stations were scheduled for interviews. This was necessary because considerable Forest use occurs during these weekends. It was felt that travel and land use characteristics on these 2 weekends could not be adequately estimated by interviewing travelers on other weekends during the survey period.

The resulting survey schedule is shown in Figure 4. It shows that a considerable reduction in manpower was achieved by combining the basic block design for every pair of interview stations. Although 7 stations were interviewed an equal number of days spread throughout the summer period in a similar fashion, only 2 stations had to be manned simultaneously for most of the summer days. The schedule shows how the basic block design was maintained. Each interview station was surveyed at least twice each month, on different weeks; also, each station was interviewed on all 5 days of the week at least twice, once during the first half of the summer season and another during the second half. The total number of days on which interviewing was scheduled is 42, and each of the 7 stations was scheduled for interviews on 16 days during the summer period.

Determination of Sample Sizes

The next step in the design of the roadside interview survey was the determination of the sample sizes. This was done separately for each interview station because the volume of traffic expected, and thus the size of the total population from which a sample was to be drawn, was different for each station. Based primarily on the expected daily traffic at each of the stations, the sample sizes determined were the number of travelers that were to be interviewed during a survey day at each of the stations.

The determination of sample sizes includes two steps. First, a statement on the expected precision of the estimates should be made; second, a relationship between precision and sample size must be constructed. This relationship is based on some a priori, or assumed, knowledge about the characteristics of the variables that are to be estimated from the sample. In the determination of sample sizes for the roadside interviews, two criteria were used. These two criteria were based on precision statements specified for two different kinds of variables that were to be estimated from the survey.

Criterion 1—An estimate of the proportion of the total traffic that is recreational is made on the basis of the observed proportion. The estimate should be within 2 percent of the true value with 90 percent confidence. This precision statement, together with the assumption that the number of recreationists traveling past a roadside station is a binomial variable, allows the establishment of a relationship between precision and sample size as follows:

$$n = \Phi^2_{.10} \frac{P(1 - P)}{d^2}$$

where

n = the sample size,

$\Phi^2_{.10}$ = the 90 percent cutoff point of the cumulative normal distribution,

P = the proportion of the total traffic that is recreational, and

d = the expected precision of the estimate, 2 percent.

If for each roadside interview station an a priori assumption can be made about P, then this formula can be used to estimate the required sample size to achieve the specified precision. The value of the sample size n thus obtained should be adjusted if the total traffic volume is small. In such a case, the required sample size, n', is obtained from n as follows:

$$n' = \frac{n}{(1) + (n/ADT)}$$

where ADT is the total daily traffic. Because the average daily traffic volume on most forest roads is relatively low (Table 1), this adjustment to the sample size was necessary.

Criterion 2—A number of variables that are estimated from the sampled interviews usually have distributions that are approximately exponential. Examples of such variables are trip length from origin to forest, duration of stay in forest, trip lengths within forest. It is required that the mean of an exponentially distributed variable be estimated with a relative precision of 10 percent. Because such variables apply only to the recreational traffic past a station, the relationship between this precision statement and the required sample size becomes

$$n = \frac{ADT_r}{1 + ADT_r \cdot d^2}$$

where

ADT$_r$ = the recreational daily traffic, and

d = the expected precision, as before (here 10 percent).

This value of n must be adjusted to yield a sample size that can be drawn from the total traffic. This adjustment is made on the basis of an a priori estimate about the proportion of recreational traffic. Thus the adjusted sample size becomes

$$n' = \frac{n}{P}$$

Sample sizes using the two criteria described were determined for all 7 roadside interview stations. The results are given in Table 1. In determining the sampling rates (i.e., the proportion of the total traffic that is to be stopped for interviewing), the highest of the two sample sizes was used.

From Table 1 it can be seen that, because the expected traffic volumes on most interview stations were so low, most of the sampling rates were 100 percent. This means that the critical factors in the design of a roadside interview survey on the road system of a national forest are the choices of survey locations and survey dates rather than the calculation of sample sizes for each station. This result could be intuitively arrived at even without performing these calculations. The argument would be that, because one has to incur the survey costs required to travel to a roadside station in the forest and sample traffic throughout a survey day period, the marginal cost incurred in surveying all traffic is negligible, especially when the total volume expected during a day is as low as 100.

CAMPGROUND INTERVIEW SURVEY

As was mentioned earlier, the campground interview survey was conducted in conjunction with the main roadside interview survey at Tahoe National Forest. This survey was conducted at a small scale for the purpose of obtaining information similar to that obtained in the main survey. This information would then be used for corroboration.

For the campground interview survey it was realized that a representative sample of a number of different campground types had to be drawn. For this reason 7 campground types were defined, as follows:

1. Campgrounds along highways;
2. Campgrounds near extra-forest activities (e.g., Reno and other Nevada recreation areas);
3. Campgrounds along minor state highways;
4. Moderately accessible lakeside campgrounds;
5. Moderately accessible campgrounds not on a lakeside;
6. Poorly accessible lakeside campgrounds; and
7. Poorly accessible campgrounds not along a lakeside.

At least two campgrounds belonging to each of the 7 campground types were identified in Tahoe National Forest. Four interview days were chosen during the survey period—2 weekdays and 2 weekend days. It was believed sufficient for the campground interview survey to identify one 2 types of days of the week rather than 5 as was the case in the roadside interview survey.

As in the roadside interview survey, the determining factor in the design of the campground survey was the requirement for a representative sample rather than a requirement for statistical precision. In the campground survey the interviewers had to interview with a sampling rate of 100 percent. This was necessary because the number of recreationists that could be found in the campgrounds during any one day was relatively low. In fact, most campgrounds had a capacity below 30 campsites. The selection of a sample size on the basis of postulated variable characteristics and statistical precision statements would have been of little meaning when the population from which to choose did not exceed 30.

SURVEY CONDUCT AND RESULTS

Based on the survey designs described, the roadside interview survey and the campground interview survey were conducted according to schedule in the summer of 1970. Roadblocks were established according to traffic engineering principles, and teams of flagmen and interviewers manned these interview stations during the designated days. Interviewers were equipped with interview forms that they filled in as they received answers to their questions from the motorists. Samples of these interview forms are shown in the Appendix to this paper. Both roadside and campground forms are shown. Because the two surveys were complementary, it can be seen that the interview forms are quite similar.

Traffic volumes on forest roads were so low that no traffic delays were caused by the roadside survey. The interviews were conducted in such a manner that their duration was reduced to approximately 2 minutes per interview. The response of the recreationists, both on the road and at the campgrounds, was excellent. Nonresponse and inconsistent information did not exceed 5 percent of the total sample drawn in either survey. It seemed that motorists in recreation areas, such as a national forest, are much more cooperative with traffic surveys than is usually experienced on urban or on nonrecreational rural roads.

A total of 7,076 recreationist roadside interviews were conducted. Of these, 2,122, or 30 percent, were one-day visitors, and the other 4,954, or 70 percent, stayed overnight in the Forest. Of the latter, 79 percent were camped in the Forest and 21 percent had stayed in other types of facilities (motels, cabins, etc.). Of 2,225 overnight Forest campers that did not reside in the vicinity of the Forest, 86 percent came from central and southern California, 9 percent from northern California, Oregon, and Washington, and 5 percent from Nevada and other states. The Appendix contains some of the results of the survey as samples of the kind of information that can be obtained from a roadside survey in a national forest. A complete description of the results of the survey is given elsewhere (1).

CONCLUSIONS

A number of conclusions can be drawn based on the experience of the national forest travel survey of the summer of 1970. Some of these conclusions apply equally to other areas that have characteristics similar to national forests.

The roadside interview method is most suitable for surveying travel in a national forest. Travelers on their way out of a forest area will find it easy to report on the activities they undertook while on their visit. Traffic volumes are low. This allows roadside interviewing to proceed safely without causing traffic delays.

In designing the survey, the requirements of a representative unbiased sample were more critical in the determination of sampling rates and survey schedules than statistical precision statements. Volumes were so low that the marginal costs of increasing sampling rates to 100 percent were negligible at most survey locations.

Survey cost reductions could be achieved by scheduling survey days in conjunction with interview locations using an incomplete block design. This design allowed a reduction in total surveying effort while at the same time it yielded a representative sample unbiased by geographic, temporal, or other variations in travel and land use characteristics.

The campground interview survey method provides a fast and economic way of obtaining most of the information needed for planning purposes and for the development of transportation analysis techniques. It seems that in areas where little is known about travel and land use characteristics it may be necessary to conduct a roadside interview survey such as the one described in this paper; however, this may not be necessary in all situations. In areas where records exist of travel characteristics and land use participation, it may be sufficient to conduct surveys at campgrounds and other recreation areas for the purpose of updating such records or for the purpose of developing analysis techniques needed in planning. Of course, campground surveys alone may give a biased sample of the users of a forest or other recreation area. This may be remedied by conducting surveys for each particular area at the facilities most predominantly used in that area.

The information obtained from the travel survey was most helpful in giving insight about activities in the national forest. This insight was a major prerequisite for the development of techniques that could be used in analyzing the operation and impact of transportation system alternatives.

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APPENDIX

SAMPLES OF DATA COLLECTED
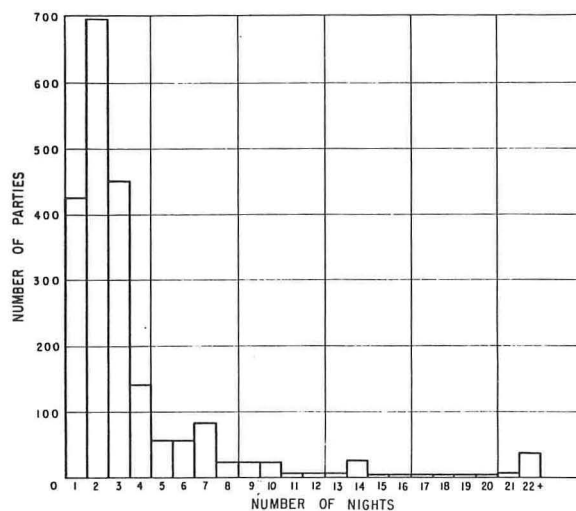
Figure A-1. Length of campers' stay.
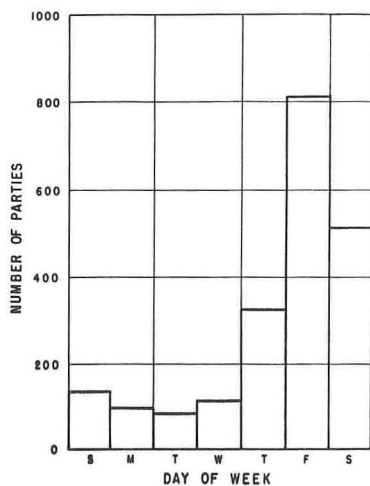

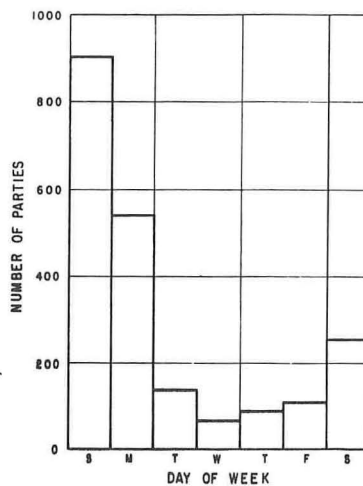**Figure A-2. Arrival day of week.**

Figure A-3. Departure day of week.

Figure A-4. Roadside interview form.

Figure A-4. Roadside interview form.

Figure A-5. Campground interview form.

Figure A-5. Campground interview form.

Table A-1. Distribution of length of stay for each party type.

Party-Type Categories	Number of Parties											
1. Families with Children (Members Under 16)	128 17%	245 33%	187 25%	60	51	37	30	5	10	2	1	6
2. Families with All Members Over 45	44 20%	68 30%	45 20%	19	18	6	5	5	2	3	0	9
3. All Other Families	94 21%	164 37%	86 20%	22	25	15	12	1	5	4	4	6
4. Groups with Children	12 15%	30 38%	18 25%	7	3	1	1	0	1	0	1	2
5. Groups with All Members Over 45	12	5	6	2	5	2	4	0	0	0	0	2
6. Groups with All Members 16-30	50	67	34	5	9	5	5	0	1	1	1	6
7. All Other Groups	26	35	10	5	0	2	1	2	1	1	1	5
8. All Organizations	1	3	8	2	1	0	0	0	0	0	0	0
Length of Stay (Nights)	1	2	3	4	5-6	7	8-10	11-13	14	15-20	21	OVER 21

Table A-2. Frequency distribution of arrival and departure day of week.

	SUN	MON	TUE	WED	THUR	FRI	SAT
Number of Parties Departing	906	542	134	61	83	101	250
Number of Parties Arriving	133	99	88	109	326	809	513
Day of Week	SUN	MON	TUE	WED	THUR	FRI	SAT

MODELS FOR RECREATION TRAFFIC ESTIMATION WITHIN A NATIONAL FOREST

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A set of travel demand models was developed to estimate recreation traffic on the transportation system of a national forest. These models were calibrated and tested on travel pattern data collected at Tahoe National Forest in California. This paper describes the models and documents their use to reproduce the observed pattern of trips to forest campgrounds. The project illustrated a two-stage approach to recreation traffic estimation by tying into statewide recreation traffic estimates produced by a second set of "macro-allocation" models. The models proved capable of reproducing 88 percent of the variation in the observed data. The set of models contains capabilities for trip generation and for trip distribution and assignment. The principal distribution and assignment model is an intervening opportunities model formulated to take the travel time between attractors explicitly into account.

•IN DEVELOPING recreation traffic estimation models for national forest planning, one quickly recognizes the significant differences between the nature of this problem and the nature of the urban and interurban problems to which planning models have traditionally been applied. Although the functions of the various models can be essentially the same—that is, one may envision procedures to perform trip generation, trip distribution, and trip assignment—it is clear that the classical and simple model sequence, beginning with generation and ending with assignment, is entirely inadequate.

A new sequence of intermodel linkages was therefore devised. The structure of these new linkages is shown in Figure 1. The figure shows five types of travel patterns that are modeled separately and then aggregated to an estimate of total national forest recreation traffic. The characteristics of these five patterns are as follows:

No. 1 is the pattern of travel from external population centers to the study forest as a whole. Because the level of detail for this analysis is considerably more aggregate than for the intraforest analyses, this problem, called "macro-allocation," is treated independently from the others. The models developed for macro-allocation are described elsewhere (1).

No. 2 is the pattern by which overnight visitors to the forest travel to their forest camping locations from convenient hypothetical locations near the forest boundary called "gates."

No. 3 is the pattern by which single-day visitors travel to their day-use recreation areas within the forest from the forest gates.

No. 4 is the pattern by which overnight visitors travel from their campgrounds to day-use recreation areas within the forest.

No. 5 is the pattern by which forest area residents travel from their homes to recreation areas in the forest.

Because of the complexity of the overall problem, work was undertaken to develop a group of models that would include techniques to handle the various trip purposes and travel patterns involved. These models are the subject of this paper.

The following two sections discuss the trip generation models and a trip distribution and assignment technique that was developed to estimate traffic for purposes such as sightseeing and hiking. The succeeding sections present in detail an intervening opportunities type of distribution model derived to be applicable to modeling recreation trips

such as those made for camping, swimming, and fishing. This is followed by an account of the calibration of this model for camping and fishing trips.

TRIP GENERATION MODELS FOR INTRAFOREST RECREATION TRAFFIC ESTIMATION

Considerable thought was given to selecting an approach to trip generation for intraforest recreation travel analysis (10). Two of the patterns shown in Figure 1 require this capability: pattern No. 4, in which trips are generated at campgrounds, and pattern No. 5, in which trips are generated at forest area residences. In both cases it was decided that the best approach is to employ trip rates at the highest possible level of disaggregation. For campgrounds, the analysis considers trip rates for camping parties; for residences, it considers trip rates per household. These rates are stratified on the basis of trip-maker socioeconomic characteristics, generation location (i.e., campground, residence) characteristics, and trip type characteristics.

The cross-classified-rates approach to trip generation was chosen because it retains the maximum amount of the original behavioral information present in the data and also because it is easy to understand and use. In this situation the latter characteristic is especially desirable because these analytical techniques are being developed not for a single study but as general planning tools to be used eventually in many national forests.

A TRIP DISTRIBUTION AND ASSIGNMENT MODEL FOR TOURING TRAVEL

Efforts were undertaken to develop a distribution and assignment model for trips that have no well-defined destinations and for which travel difficulty is a relatively small influence. These trips are called "tours" and correspond to purposes such as sightseeing, trail-bike riding, and hiking.

This model is a significant departure from traditional approaches to traffic estimation. Rather than dealing with origin-destination volumes, the model directly estimates the traffic flow on every link of the transportation network. This is done by attempting to satisfy a priori estimates of relative link popularity using a linear program to minimize the differences between a priori and calculated popularity. The traffic is determined subject to constraints on trip generation levels, average trip length, and conservation of network flows. This model, which is the subject of another paper by the author (8), is not described further here.

THE IMPEDANCE-DEPENDENT OPPORTUNITY MODEL

In selecting a method to perform trip distribution to well-defined forest recreation areas such as campgrounds and lakes, it was decided that no existing model was really suited to the problem at hand. Specifically, it seems that the principal existing models are too simplistic in their manners of representing the spatial patterns of destinations. Both of the two most popular distribution models, the gravity and intervening opportunities models, use but a single metric to account for relative position. The metric employed in each model is different, however; travel impedance (distance, cost, and/or time) is used in the former and a measure of bypassed destination opportunities in the latter (2, 3).

In study areas containing a dense pattern of destinations, there has been shown to be very little difference, in practice, between the two principal measures of relative location (4). This is because both of the measures tend to change in fixed proportion to one another. Therefore, in such situations, if one accounts for one of the two phenomena, he actually accounts for both. This fact explains the similar degrees of success achieved by gravity and opportunity models in performing urban trip distribution.

But under the conditions found in a national forest, the alternative methods of measuring relative location are not at all equivalent. Because of clustering and topographic irregularities, there is no proportionality between the travel impedance overcome and the number of potential destinations intercepted. For this reason it was felt that the

proper model for the national forest situation would be one that explicitly considered both opportunities and travel impedance in determining the distribution of trips. Such a model was derived using the entropy-maximizing procedure advocated by Wilson (5, 6). This new model was christened the "impedance-dependent opportunity model" (7).

This is not the first time that the separate measures of travel impendance and by-passed opportunities have been combined in the same model. However, the only other similar combination that was found appears in a short paper by Harris (4) where he concerns himself with the mathematical form that a distribution model takes if impedance and bypassed opportunities are either (a) proportional or (b) separate independent phenomena. In the latter case, he derives a distribution model similar to the impedance-dependent opportunity model, the difference being in the assumption that, here, the two measures are separate but non-independent quantities.

The impedance-dependent opportunity model operates by calculating the probabilities of trips stopping at destinations according to their relative proximity to the trips' origins. As in the intervening opportunities model, the probability of stopping at a destination is related to its relative attractiveness and to the total attractiveness of all destinations closer to the origin. Unlike the standard model, however, the probability of stopping is also related to the extra travel that would be incurred in passing up the given destination to go at least as far as the next one. The model is therefore sensitive to two characteristics that seem to affect the destination choices of trip-makers—the order in which the destinations can be reached and the impedance experienced in reaching them.

DERIVATION OF THE IMPEDANCE-DEPENDENT OPPORTUNITY MODEL

The derivation of the model requires that the following symbols be defined:

i—A subscript identifying a particular trip origin, that is, a location where trips are generated ($i = 1, 2, \ldots, M$).

j—A subscript denoting the rank of a particular trip destination in relative proximity to a given origin ($j = 0, 1, 2, \ldots, N$). ($j = 0$ denotes the origin itself.) Note that a given destination's j value is a function of the origin under consideration and consequently cannot be used to uniquely identify the place itself.[*]

t_{ij}—The number of trips between origin i and destination j.

$\{t_{ij}\}$—The set of t_{ij}'s for all (i, j). This set is called the "trip distribution pattern."

S_{ij}—The number of trips between origin i and all destinations farther away from i than destination j. [Note that this is the variable employed to derive the intervening opportunities model (3).]

$\{S_{ij}\}$—The set of S_{ij}'s for all (i, j). This set also is called the "trip distribution pattern" because it is equivalent to $\{t_{ij}\}$. One can always compute $\{t_{ij}\}$ from $\{S_{ij}\}$, and vice versa, as follows:

$$t_{ij} = S_{ij-1} - S_{ij}$$

$$S_{ij} = \sum_{\ell=j+1}^{N} t_{i\ell}$$

S—The sum $\sum_{i=1}^{M} \sum_{j=0}^{N} S_{ij}$.

M—The total number of origins.

N—The total number of destinations.

Note that, in general, the number of origins is not equal to the number of destinations.

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[*]Strictly speaking, the subscript j should be written to show its dependence on i—for example, as $j(i)$ or j_i. However, to avoid cluttering the derivation with subscripts upon subscripts or other cumbersome devices, the relationship between j and i is left implicit.

Given these definitions, one can write an expression for the likelihood of a trip distribution as follows:

$$\frac{S!}{\prod_{ij} (S_{ij}!)}$$ (1)

This is an expression for the number of ways the total quantity of S units can be divided into the M × N bundles of certain size, S_{ij}, that constitute a particular trip distribution, $\{S_{ij}\}$.[*] Since the quantities of interest in a trip distribution are the sizes of the bundles (i.e., the quantities S_{ij}) and not the individual units themselves, Eq. 1 represents the likelihood of occurrence of the set of bundles, S_{ij}, under the assumption that, in the absence of constraints, each of the S units is as likely to be found in one origin-destination state as another. On the basis of the argument that the expression for the likelihood of a trip distribution is proportional to its probability, Wilson maximizes Eq. 1 to find the most probable trip distribution. If one assumes that the most probable distribution is the one observed in the real world, the expression representing that distribution is employed as its model.

When one maximizes Eq. 1 subject only to $\Sigma S_{ij} = S$, one finds that the most probable distribution is that for which all the S_{ij}'s are equal. In order to make the distribution nontrivial, it is necessary to specify a set of constraints to impose the desired reality upon the trip pattern. Before doing this, it is necessary to define some additional symbols:

O_i —The number of trips emanating from origin i $\left(O_i = \sum_j t_{ij}\right)$.

D_j —A measure of the inherent attractiveness of destination j. In the case of national forest traffic estimation, this measure is computed by a factor analysis technique described elsewhere (9). This measure is considered to represent the number of opportunities for trip purpose satisfaction present at destination j.

A_j —The sum of the measures of attractiveness at destination j and all destinations closer to the origin than j:

$$\left(A_j = \sum_{\ell=1}^{j} D_\ell\right)$$

Q_j —The impedance to travel between a given destination, j, and the next available destination farther away from the origin.

Given these, it is possible to define the three constraints that determine the structure of the impedance-dependent opportunity model:

Constraint 1: The number of trips distributed from each origin is a fixed known quantity, O_i. Thus,

$$\sum_{j=0}^{N} S_{ij} = k_i O_i \quad \text{for} \quad i = 1, 2, \ldots, M$$ (2)

where the k_i are parameters with values between 1 and N.

The interpretation of the k_i is that each is the average rank of the destinations relative to origin, i, weighted by the numbers of trips to those destinations. That is,

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[*]It is not obvious how one should interpret units of S. It seems to be easiest to conceptualize them as "destination bypassing activities." However interpreted, it is essential that these quantities be viewed as collections of discrete units that can theoretically be rearranged in a large number of different ways.

$$k_1 = \frac{t_{11} + 2t_{12} + 3t_{13} + \ldots + Nt_{1N}}{\displaystyle\sum_{j=1}^{N} t_{1j}} \tag{3}$$

Note that, by inserting Eq. 3 into Eq. 2 and substituting $\displaystyle\sum_{\ell=j+1}^{N} t_{1\ell}$ for S_{1j}, Eq. 2 becomes

$$\sum_{j=1}^{N} t_{1j} = O_1 \tag{2'}$$

which is a more easily understood form for this constraint.

Constraint 2: The number of trips from an origin to any destination is influenced by the order in which all destinations can be reached from that origin and also by the impedance that must be overcome in passing up a given destination to travel at least as far as the next one.

Sensitivity to the order in which destinations can be reached is imposed upon the model by introducing a fixed limit on the amount of bypassing of opportunities that can occur in a travel pattern. The constraint on bypassing opportunities is made sensitive to additional impedance by setting different limits on the amount of bypassing that can occur at destinations having different impedances:

$$\sum_{i=1}^{M} \sum_{j\in\{J_m\}} A_j S_{1j} = P_m, \text{ for } m = 1, 2, \ldots, R \tag{4}$$

where

$\{J_m\}$—The set of all j subscripts for which Q_j, the impedance, falls within a range of values identified by the subscript m. There are R such sets, one of which identifies the set of destinations where the quantity Q_j is not explicitly defined—that is, destinations at the extremities of the network. This concept is shown in Figure 2.

P_m—A constant limit on the total number of opportunities that may be bypassed at destinations with subscripts in the set $\{J_m\}$.

R—The number of sets $\{J_m\}$.

Constraint 2 can be called the "opportunity model constraint." Wilson (5) has shown how maximizing Eq. 1 subject to these first two constraints (without the "$\overline{m}$" subscripts in constraint 2) leads to the standard expression for the intervening opportunities model.

Constraint 3: The number of trips that bypass a given destination is inversely related to the difficulty of traveling to the next available destination. The structure of this constraint is analogous to that of constraint 2:

$$\sum_{i=1}^{M} \sum_{j=0}^{N} Q_j S_{1j} = C \tag{5}$$

Here C represents a fixed limit on the total travel cost that can be consumed in the system. Like the P_m of constraint 2, it is not necessary to actually know the value of C, but simply to acknowledge that, under a given equilibrium of supply and demand, such a limit exists. The interpretation of C becomes easier if Eq. 5 is expressed in terms of t_{1j}:

$$\sum_{i=1}^{M} \sum_{j=0}^{N} Q_j S_{1j} = C \tag{5}$$

$$\sum_{i=1}^{M} \sum_{j=0}^{N} Q_j \left(\sum_{\ell=j+1}^{N} t_{1\ell} \right) = C$$

$$\sum_{i=1}^{M} \sum_{j=1}^{N} \left(\sum_{\ell=0}^{j-1} Q_\ell \right) t_{i j} = C^* \tag{5'}$$

Note that $\sum_{\ell=0}^{j-1} Q_\ell$ is the total impedance between the origin and the jth destination.

The impedance-dependent opportunity model can now be derived by maximizing Eq. 1 subject to the three constraints (Eqs. 2, 4, and 5). Because of the complexity of Eq. 1, it is more convenient to maximize its logarithm. The logarithm is

$$\ln S! - \sum_{ij} \ln S_{i j}! \tag{1'}$$

Expression 1′ is further simplified by employing Stirling's approximation (i.e., $\ln N! \approx N \ln N - N$) to obtain

$$\ln S! - \sum_{ij} (S_{i j} \ln S_{i j} - S_{i j}) \tag{1''}$$

Expression 1″ is maximized subject to the constraints by taking the partial derivative, with respect to $S_{i j}$, of

$$R = \ln S! - \sum_{ij} \left(S_{i j} \ln S_{i j} - S_{i j} \right) + \sum_{i} \lambda_i \left(k_i O_i - \sum_{j} S_{i j} \right)$$
$$+ \sum_{m} L_m \left(P_m - \sum_{i} \sum_{j \in \{J_m\}} A_j S_{i j} \right) + \beta \left(C - \sum_{i} \sum_{j} Q_j S_{i j} \right)$$

where the λ_i's, the L_m's, and β are Lagrange multipliers. This yields

$$\frac{dR}{dS_{i j}} = - \ln S_{i j} - \lambda_i - L_m A_j - \beta Q_j = 0$$

which gives

$$S_{i j} = \exp (-\lambda_i - L_m A_j - \beta Q_j) \tag{6}$$

By substituting Eq. 6 into Eq. 2, the Lagrange multipliers λ_i can be determined as follows:

$$\sum_{j} \exp (-\lambda_i - L_m A_j - \beta Q_j) = k_i O_i$$

$$\exp (-\lambda_i) = k_i O_i \left/ \left[\sum_{j} \exp (-L_m A_j - \beta Q_j) \right] \right.$$

Then, by defining

$$K_i = k_i \left/ \left[\sum_{j} \exp (-L_m A_j - \beta Q_j) \right] \right. \tag{7}$$

Eq. 6 can be rewritten as

$$S_{i j} = K_i O_i \exp (-L_m A_j - \beta Q_j) \tag{6'}$$

Equation 6′ is the theoretical form of the impedance-dependent opportunity model. The model is more conveniently expressed in terms of trips, as follows:

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*The step from the second equation to Eq. 5′ is not obvious unless one expands the summations of the former and then regroups the terms according to the summations of the latter.

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Figure 1. The components of national forest recreational travel.

- Single Day Visits
- Overnight Visits
- Campgrounds
- Day Use Recreation Facilities
- Communities Outside Forest Area
- Communities Inside Forest Area
- Travel Pattern Label (See Text)
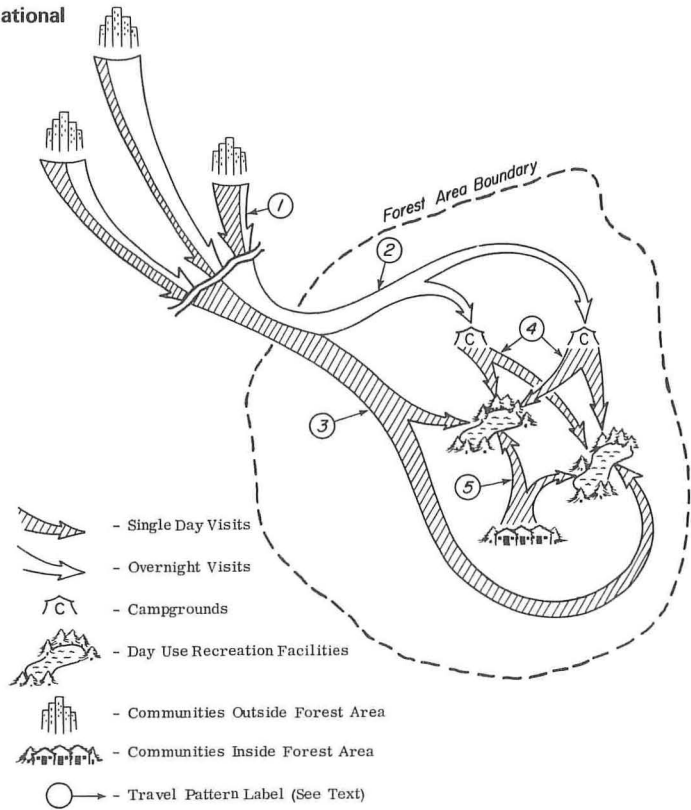
Figure 2. The measurement and grouping of destination impedances.
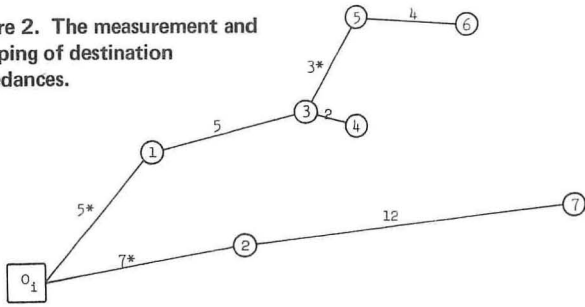
Destination	1	2	3	4	5	6	7
Associated Impedance, Q_j	5	12	2	#	4	#	#

Grouping (m=)	1	2	3
Impedance Range (Q_j=)	0 - 4	5 - ∞	extremities
Included Destinations $\{J_m\}$	3, 5	1, 2	4, 6, 7

Legend:
☐ represents the trip generator
◯ represents ranked destinations
# indicates a destination on the network extremity
The numbers on the links are their impedance values

$$t_{1j} = K_1 O_1 \left[\exp(-L_m, A_{j-1} - \beta Q_{j-1}) - \exp(-L_m A_j - \beta Q_j) \right] \qquad (8)$$

To facilitate calibration and to overcome the difficulty of having no explicit measures of the impedances Q_j for destinations at extremities of the transportation network, the model terms βQ_j were replaced by parameters represented by B_m. A value of B_m is computed for each set of destinations $\{J_m\}$ with similar impedance characteristics. This yields the final practical expression for the model,

$$t_{1j} = K_1 O_1 \left[\exp(-L_m, A_{j-1} - B_m,) - \exp(-L_m A_j - B_m) \right] \qquad (9)$$

where m' identifies the set J_m, that includes destination $j - 1$.

MODEL CALIBRATION RESULTS

As a test of its suitability for recreation travel, the new distribution model was applied to reproducing the intraforest portions of trips by overnight forest visitors to their campgrounds—that is, travel pattern No. 2 of Figure 1. This trip type was chosen for the first model calibration attempt because it is clearly the most important with respect to investment decisions for forest recreation facility development. It is also a key trip type with respect to other travel pattern analyses, because any estimates of campground-based trip-making are necessarily dependent on prior determination of campground occupancy.

The use of the first camping trip to illustrate the applicability of the model to forest recreation travel is especially challenging. There is a risk that, after driving a substantial distance to reach a national forest, travelers are then no longer sensitive to differences in the relative proximity of campgrounds within that forest. An extra hour of travel time may not be important in the campground selection of a recreationist planning a 3- or possibly 4-hour home-to-campground trip. If differences in distance traveled within the forest are, in fact, irrelevant with respect to campground selection, then that would completely invalidate the assumptions on which the model is based. As it turned out, there is cause to anticipate a lack of sensitivity to intraforest travel time on the part of some travelers. However, it was found that insensitivity to impedance is apparently restricted to a subset of travelers who patronize special highly attractive campground developments, and camping trips that do not fall into this category are very amenable to being simulated by the new model.

The method of calibration for the impedance-dependent opportunity model is similar to that of the intervening opportunities model. First, the model is expressed in terms of the variables S_{1j}, as follows:

$$t_{1j} = S_{1j-1} - S_{1j} \qquad (10)$$

where

$$S_{1j-1} = K_1 O_1 \exp(-L_m, A_{j-1} - B_m,)$$

and

$$S_{1j} = K_1 O_1 \exp(-L_m A_j - B_m)$$

Dividing through by $K_1 O_1$ and taking the logarithm yield the general relationship

$$\ln(S_{1j}/K_1 O_1) = -L_m A_j - B_m$$

During model calibration the normalization constant, K_1, is unity and can be dropped. To determine the values of the parameters, a straight line is fitted for each group of destinations, $\{J_m\}$, having similar impedance characteristics. The L_m and B_m are computed as the slope and intercept respectively of each line.

An attempt was made to fit the impedance-dependent opportunity model to roadside interview survey data describing 2,058 trips from 3 major forest gates to 43 camp-

grounds within Tahoe National Forest [see Fig. 1 of Kanafani (11)]. For trips of this nature, it seemed reasonable to stratify the destination campgrounds into three groups:

1. Campgrounds that can be bypassed without a significant travel penalty because another campground is close by—specifically, within a 10-minute drive;

2. Campgrounds whose bypassing involves a noticeable travel penalty, that is, 10 minutes or more;

3. Campgrounds that cannot be bypassed because they are at extremities of the network with respect to the locations of the forest gates. In a sense, the impedance penalty associated with these destinations is equivalent to the reluctance to backtrack.

The capacities of the campgrounds, in terms of the numbers of units available, were used to measure the bypassed opportunities. Note that these capacities bear only a weak relationship to the numbers of trips actually attracted to the various campgrounds. The model, therefore, serves as a campground utilization model as well as a trip distribution model.

When the trip data were plotted preparatory to computing the intercepts, B_n, and slopes, L_n, a curious phenomenon manifested itself in each of the three diagrams corresponding to the three impedance groups. The points, rather than falling along the anticipated straight line, clearly fell along a curve. This is shown for one of the three impedance groups in Figure 3.

Further analysis was undertaken to investigate this phenomenon. In doing so, an interesting conclusion was reached that pertains to the calibration of intervening opportunities models in general. It was determined that the cause of the nonlinearity was the fact that at least some of the trip-making represented in the data does not attenuate over distance. In other words, a significant number of trips exhibit lack of sensitivity to the spatial pattern of the destinations. This type of distribution can be described by a simple proportional model of the form

$$t_{ij} = O_i D_j \left/ \sum_{k=1}^{N} D_k \right. \tag{11}$$

It can be shown that this expression is equivalent to

$$S_{ij}/O_i = 1 - A_j/A_n \tag{11'}$$

which, upon taking the logarithms, yields the shape of the curve in Figure 3.

The implication of this finding is that there are campers who are insensitive to the difficulty of reaching their destinations. Since it does not seem reasonable to believe that all campers behave this way, an effort was made to find an identifiable subset of impedance-insensitive camping trips that could be isolated from the rest. Upon analysis, it was found that insensitivity to impedance is primarily found among trips made to lakeside campgrounds, a set dominated by four extremely attractive and rather inaccessible developments. When these trips were removed, the remaining 1,024 trips, those to 27 non-lakeside campgrounds, fitted the structure of the impedance-dependent opportunity model very well.

Figures 4, 5, and 6 show the final calibration curves for the three impedance groups. Note that these patterns correspond very closely to the theoretical linearity. The computed parameter values are as follows:

Impedance Group	L_n	B_n	Sample	Correlation Coefficient	Standard Error
0 to 9.99 min	0.0203037	0.0815182	15	0.9803	0.00333
10 min and greater	0.0180142	0.1546793	19	0.9757	0.00099
Network extremities	0.0201420	0.1449599	18	0.9390	0.00361

Once calibrated, the model was used to reproduce the observed trip pattern. Figure 7 shows the cell-by-cell comparisons between the observed and model-reproduced trip

Figure 3. Calibration curve for 43 campgrounds—impedance less than 10 minutes.
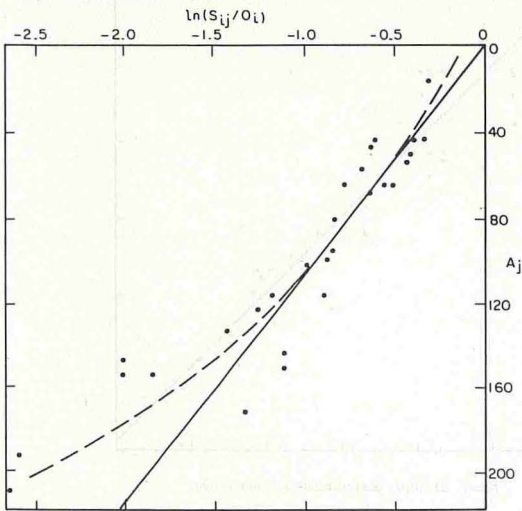
Figure 4. Calibration curve for 27 campgrounds—impedance less than 10 minutes.
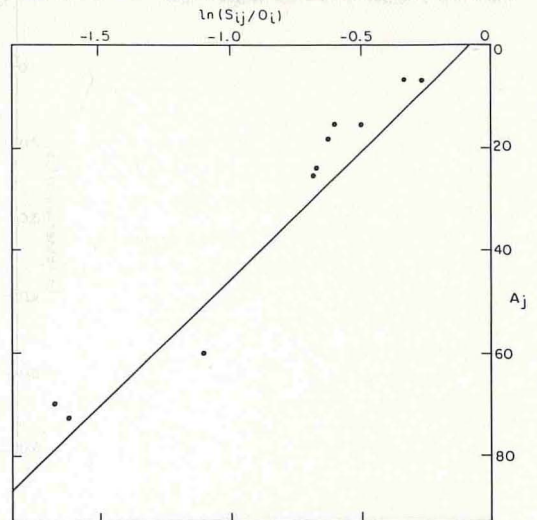
Figure 5. Calibration curve for 27 campgrounds—impedance 10 minutes and more.
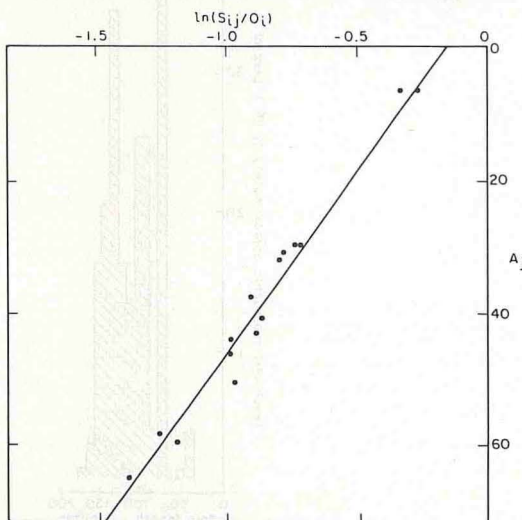
Figure 6. Calibration curve for 27 campgrounds—destinations at network extremities.

48
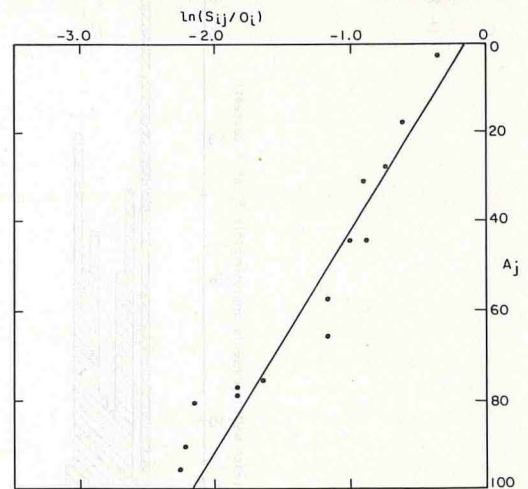
Figure 7. Comparison of modeled versus observed
trip interchanges for 27 campgrounds.
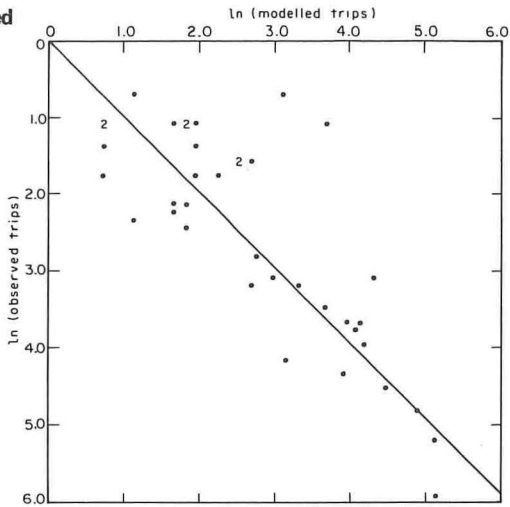
Note: 91 (0,0) observations are not shown.

Figure 8. Observed trip
length frequency diagram for
27 campgrounds.

Figure 9. Modeled trip
length frequency diagram for
27 campgrounds.

interchanges. The correlation coefficient between the observed and model-reproduced trips is 0.94, an R^2 of over 0.88, which indicates that over 88 percent of the variation in the data is explained by the model. Figures 8 and 9 show the observed and model-reproduced trip length frequency distributions. Note that, in this case, the model almost exactly reproduced the average trip length, estimating 102.61 minutes co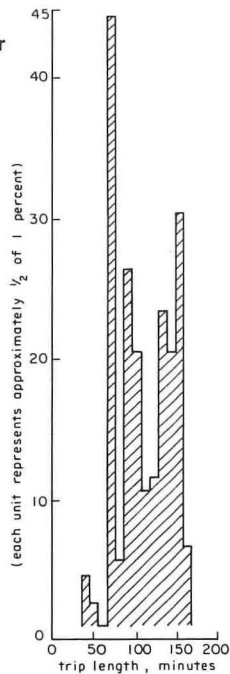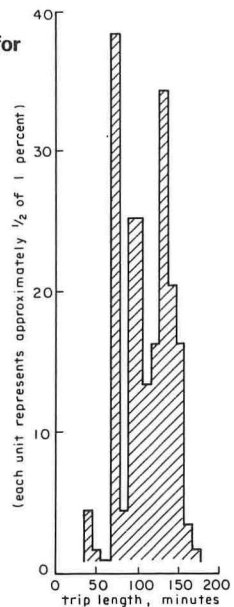mpared to the observed value of 102.55. This was achieved without the use of ad hoc parameter adjustments often employed in the calibration of trip distribution models.

To test the reproducibility of the trips that could not be modeled by the impedance-dependent opportunity model, the simple proportional distribution model, Eq. 11, was employed. This model reproduced the observed pattern with a correlation coefficient of 0.82, which is an R^2 of about 0.67. Although this fit is not as good as the former, it is considered adequate for the planning applications to which these models are put.

The degree of success achieved in this initial attempt to model an intraforest recreation travel pattern appeared to verify the basic assumption that, at this level of aggregation, the activities of forest visitors are sufficiently regular that mathematical planning models can be applied.

The impedance-dependent opportunity model is theoretically applicable to any travel pattern in which the destinations are well defined and substitutable and where the difficulty of travel influences the destination choice. A number of travel patterns in national forests have these characteristics. To further test its capabilities, the model was applied to the intraforest portions of single-day fishing trips to lakes. This pattern is type 3 as shown in Figure 1.

After a calibration process similar to that already described, it was found that the model reproduced the fishing-trip travel pattern with a correlation coefficient of 0.74—that is, an R^2 of about 0.55. The model estimated the average trip length as 90.79, as compared to the observed average length of 91.01. Although the model was not as successful in reproducing this pattern as it was in the case of camping trips, it seems reasonable to suggest that this level of accuracy is commensurate with that normally accepted for planning models. In the future, additional experience gained in fitting this model to other travel patterns in different forests will fully define the range of its applicability.

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A MODEL FOR ALLOCATING RECREATIONAL TRAVEL DEMAND TO NATIONAL FORESTS

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This paper documents the development of a model for allocating travel demand and the subsequent application of this model to allocate recreational demand from the centers of population in California to the main entrances of the national forests in California. The model, which is based on the principles of systems analysis, first decomposes the recreational system into a set of origin components, destination components, and travel link components. Each of these classes of components is then modeled separately in terms of its characteristics. The final model is the aggregation of the mathematical description of each component and the mode of interconnection of the components. The model has the capability of allocating travel demand in one step. The results of its application to California proved its ability to simulate the recreational travel system.

•THIS PAPER describes the development and application of an analytical model for allocating recreational demand from population centers in California to the national forests in the state. The work described is part of a package of analytical techniques developed at the University of California, Berkeley, to aid the U. S. Forest Service in its resource management planning process.

In planning for resource management in a national forest it is necessary to estimate the future recreational travel demand and the spatial distribution that it will follow. This estimation process is accomplished by a set of analytical models based on (a) the locations and characteristics of the forest resources and developed recreation areas; (b) the characteristics of the forest transportation system; (c) the locations and characteristics of population centers within a reasonable journey time to the forest; (d) the characteristics of the regional transportation system that links the population centers to the study forest; (e) the locations and characteristics of "competing" recreational complexes in the area; and (f) knowledge concerning the travel behavior of recreationists.

These analytical models deal with two levels of problem. The first problem is one of estimating the number of visitors that will be drawn to the study forest from the surrounding population centers. The second problem is to predict how these visitors, once there, will disperse to the many possible locations within the study forest. In order to deal with the bi-level nature of the problems without overemphasizing one level at the expense of another, two distinct allocation levels were modeled. They are the "macro-allocation" stage, which estimates the number of visits from the population centers to the study forest as a whole, and the "micro-allocation" level, which estimates the traffic on the forest roads and to the forest recreational areas.

The development of a macro-allocation model, based on systems analysis techniques, and the application of this model to allocate recreational flows to the national forests in California are described in the following sections.

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THEORETICAL FRAMEWORK OF MODEL

Choice of Approach

The systems model described next was selected for analyzing the macro-allocation of recreational trips. This choice was based on a review of literature concerning available models as well as an investigation of possible new approaches to modeling macro-allocation. It was concluded from earlier applications (1, 2, 3) that the systems model could be suitable for this problem if it were modified to improve its behavioral content and its predictive power.

Description of the Model

The systems model is based on a body of analytical techniques developed to simulate the behavior of certain physical systems. These techniques have the ability to characterize completely the interactive properties of a system by formulating a set of simultaneous equations that mathematically describe all components of the system and their mode of interconnection. Certain general steps are followed in the analysis of any system by this method. These steps, which are described in detail below, are shown in Figure 1.

The first step in the analysis of a system is the choice of units of the system as components. This choice generally depends on the type of system being analyzed as well as the purpose of the analysis. Specifically applied to the allocation of recreational travel demand to recreation areas, three classes of components are identified: (a) generating areas, or origins; (b) impedance components, or transportation links; and destination components, or national forests.

The second step in the analysis is the mathematical description of the components selected in step 1. This description is associated with two fundamental measurements of the components. In the purely physical systems (electrical, mechanical, heat transfer, etc.) these measurements are such that one is a "through" or "series" measurement, denoted Y, and the other an "across" or "parallel" measurement, denoted X. In the recreational system the through variable is the flow of recreationists in the system while the across variable is the propensity causing this flow.

Once the components have been selected and the basic measurements chosen, it is possible to formulate equations describing the system characteristics. These equations, called component terminal equations, have the general formula

$$Y = k \cdot f(\Delta X) \tag{1}$$

where k is a constant that depends on component parameters and X and Y are the fundamental measurements. The terminal equations of the three classes of components in the recreational system are derived in the following sections.

The Origin or Demand Components

The origin components were considered as sources of flow of recreationists. These are counties or groups of counties and some out-of-state areas. The general equation for the origins was

$$Y_i = known$$

The known flows are the output of a macro-generation model (4) developed for the purpose. No attempt will be made here to describe this model in detail. As specifically applied to recreational trip generation in California, the model had the formulation

$$Y_i = 138.6 \ P_i^{0.385} \ D_i^{0.025} \tag{2}$$

for day trips and

$$Y_i = 88.3 \ P_i^{0.382} \ D_i^{0.137} \tag{3}$$

for overnight trips, where

Y$_1$ = the total recreational demand at origin i;
P$_1$ = the population of origin zone i; and
D$_1$ = accessibility of origin zone i to all national forests in California; i. e.,

$$D_1 = \sum_j A_j d_{1j}{}^{\gamma_1} \tag{4}$$

where

γ_1 = -1.90 for day trips,
γ_1 = -1.50 for overnight trips,
A$_j$ = attraction index of the forest j, and
d$_{1j}$ = travel time from zone i to the forest j.

The Transportation Links

The class of system components comprising the transportation links is analogous to electrical resistance. At the macro-level, travel corridors are used as the travel links. The performance of each link is related to its travel impedance by the equation

$$Y_{11} = K_1 \frac{1}{(R_{11})} K_2 \, \Delta X_{11} \tag{5}$$

where

Y$_{11}$ = the link flow through link i;
X$_{11}$ = the propensity to travel across link i;
R$_{11}$ = the link resistance of link i; and
K$_1$, K$_2$ = calibration constants.

The link resistance was assumed to be the total cost to the recreationists in traversing the link. This includes out-of-pocket costs, costs associated with travel time, costs associated with aesthetics, etc. It is interesting to point out that some of these costs might be negative. This is true for scenic routes where a longer distance on travel time might be desirable. As other modes of transportation become available for forest recreational travel, costs associated with arrival time variability and waiting time en route will have to be considered.

The resistance factor can be represented by the product of a link performance vector and an associated cost vector as follows:

$$R_1 = LPV \times ACV = \begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{bmatrix} \tag{6}$$

where

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \end{bmatrix} = \begin{bmatrix} \text{travel time en route} \\ \text{waiting time en route} \\ \text{arrival time variability} \\ \text{aesthetic coefficient} \\ \text{travel distance} \\ \text{tolls} \end{bmatrix}$$

and C$_1$, C$_2$, ..., C$_6$ are costs associated with the L's.

In this study it was possible to take into consideration only the total travel times and the tolls paid in traversing a link.

The Destination Components

The destination areas, the national forests, are modeled by equations that relate their attraction potential to their physical attractiveness. The latter is based on the physical and natural resources of the forest and the facilities and services provided to support these activities.

The equation for the destination areas is

$$Y_{di} = K_3 \, A_{di} \, f(\Delta X_{di}) \tag{7}$$

where

Y_{di} = attracted trips to destination i;
ΔX_{di} = the potential for recreational trip attraction;
K_3 = the attraction calibration constant; and
A_{di} = the attraction index of forest i.

Both the attracted trips, Y_{di}, and the potential for trip attraction, ΔX_{di}, are unknown in this equation. The attraction index, A_{di}, can, however, be obtained as the output of a macro-attraction model. A detailed description of this model, including its theoretical development, methodology, and analysis of results, is given elsewhere (4). An attraction index is a quantity that describes the relative attractiveness of a forest with respect to competing recreation complexes for a particular type of recreational trip. Three factors govern the value of this index: (a) the outdoor recreational activity preference of recreationists; (b) the on-site natural resources that enhance the recreational experience; and (c) the on-site facilities and services that complement the recreational resource. The natural resources in a forest determine the nature of the activities possible, while the facilities and services condition the activity opportunities. The interconnection among these three elements is shown in Figure 2.

It is possible to quantify or index the attractiveness of a forest if the three elements are identified and quantified. Table 1 gives the participation rates of recreational activities in the United States, and Table 2 gives the characteristic variables of a forest with the corresponding rating scores. Finally, Table 3 gives the attraction indices for the 18 national forests in California.

Formulation and Solution of the System Equations

Once the classes of recreational system components have been selected and modeled, it is possible to formulate mathematical equations to describe quantitatively the interaction of the components of the systems. The technique used to accomplish this depends on the nature of the system. For the analysis of the recreational system the linear graph technique was used.

The construction of the linear graph for the forest recreational system follows the same steps as those used for the physical systems. The first step is the representation of each of the components by its terminal graph. The second step is to join together, by their vertices, the component terminal graphs so that the resultant is in one-to-one correspondence with the union of the physical system. Figure 3 shows a simple transportation system with its corresponding linear graph.

Like other systems, the recreational system obeys the "cutset" and "circuit" postulates. The "cutset" postulate, which is a generalization of Kirchoff's current law, states that the algebraic sum of the flows at any node equals zero. The justification of this postulate in traffic flow is that, if there is no storage within the system, then there is a continuity of flow in the system and what goes in must come out.

The circuit postulate, on the other hand, equates the potential to travel around a closed circuit to zero. The basis of this postulate in traffic flow is that as a recreational trip from a node progresses the original desire for the trip dissipates and reduces to zero by the time a closed circuit is completed.

Figure 1. Steps in the solution of a system by linear graph methods.


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IDENTIFICATION OF THE
SYSTEM COMPONENT BY
PURPOSE OR FUNCTION

THE MEASUREMENTS
OF
COMPONENTS

TERMINAL EQUATIONS
OF
SYSTEM COMPONENTS

CONSTRUCTION OF
THE
SYSTEM GRAPH

ESTABLISHMENT OF A TREE
ON THE
SYSTEM GRAPH

FORMULATION OF
THE
SYSTEM EQUATIONS

NUMERICAL SOLUTION
OF
EQUATIONS
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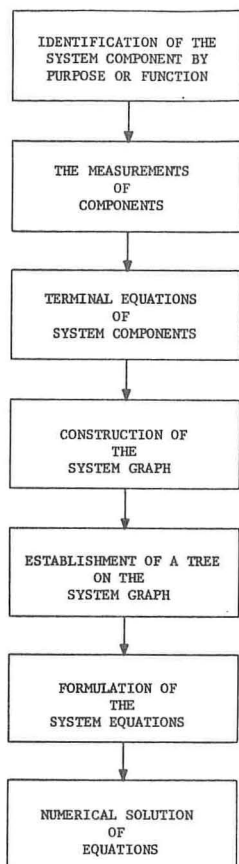
Figure 2. Interrelationship of natural resources, activity preferences, and facilities and services.
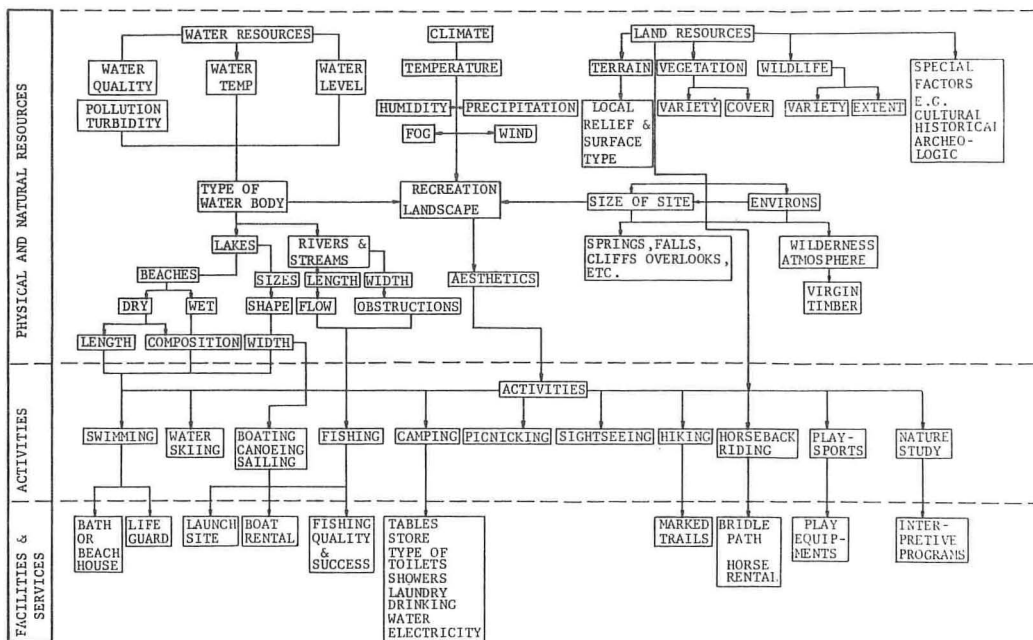
Table 1. Participation rates for outdoor recreational activities in the United States.

Activity	Percent Participation	Activity	Percent Participation
Picnics	53	Attending outdoor concerts, etc.	9
Driving for pleasure	52	Camping	8
Swimming	45	Hiking	6
Sightseeing	42	Horseback riding	6
Walking for pleasure	33	Water skiing	6
Playing outdoor games	30	Miscellaneous	5
Fishing	29	Hunting	3
Attending outdoor sports	24	Canoeing	2
Other boating	21	Sailing	2
Nature walks	14	Mountain climbing	1
Bicycling	9		

Source: National Recreation Survey, Study Report No. 19 (U.S. Govt. Printing Office, 1962).

Table 2. Forest characteristics.

Variable	Score
1. Lake acreage	10,000 acres
2. Swimming quality	Sand—5, gravel—4, timbered—3, soil mud—2, rock—1, none—0
3. Presence of designated and protected swimming areas	Present—1, absent—0
4. Boat launching facilities	Present—1, absent—0
5. Lake fishing quality	Excellent—4, good—3, fair—2, poor—1, none—0
6. Stream and river fishing quality	Excellent—4, good—3, fair—2, poor—1, none—0
7. Presence of lifeguard	Present—1, absent—0
8. Boating quality	Excellent—4, good—3, fair—2, poor—1, none—0
9. Boating restrictions	Normal—3, speed-limit—2, no-motor—1, no-boating—0
10. Bath house	Yes—1, no—0
11. Local relief	Mountainous—4, hilly—3, rocky—2, flat—1
12. Land reform	Resources present—1, resources absent—0
13. Vegetation type	Evergreen—4, mixed evergreen and deciduous—2, deciduous—2, barren—1
14. Presence of virgin timber	Virgin—2, mixed—1.5, cut-over—1
15. Presence of unusual vegetation	Present—1, absent—0
16. Extent of cover shade	Over 75 percent shaded—4, 50-75 percent shaded—3, 25-50 percent shaded—2, 10-25 percent shaded—1, under 10 percent shaded—0
17. Special factors	Number of special features
18. Quality of backwoods areas	No detractions—5, minor detractions—4, substantial detractions—3, serious detractions—2, unacceptable detractions—1
19. Quality of wildlife habitat	Excellent—3, normal—2, poor—1
20. Store at camp	Out of site—2, on site—1
21. Showers	Yes—1, no—0
22. Toilet type	Combination—3, flush—2, pit—1
23. Laundry	Yes—1, no—0
24. Electricity	Yes—1, no—0
25. Marked bridle trails	Yes—1, no—0
26. Boat rental	Yes—1, no—0
27. Horse rental	Yes—1, no—0
28. Children's play equipment	Play sports—1, equipment—2

Table 3. Attraction indices of national forests.

Forest Name	Attraction Index	Forest Name	Attraction Index
"A"	0.76	"J"	0.21
"B"	0.53	"K"	0.31
"C"	0.69	"L"	0.98
"D"	0.68	"M"	0.47
"E"	0.25	"N"	0.45
"F"	0.25	"O"	0.93
"G"	0.62	"P"	0.71
"H"	0.18	"Q"	0.73
"I"	0.16	"R"	0.53

Figure 3. Transportation system (left) and linear graph of transportation system (right).
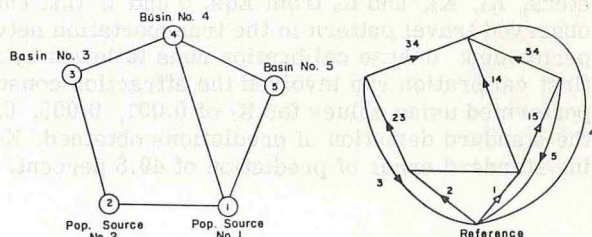
These postulates yield two sets of systems equations. One set of equations can be written for the through variables, Y, at each vertex of the system linear graph. Symbolically, this set of equations can be written as

$$\sum_{j=1}^{e} a_j Y_1 = 0$$

where

$$a_j = \begin{cases} 0 \text{ if the } j\text{th element is not incident at the } k\text{th vertex;} \\ 1 \text{ if the } j\text{th element is oriented away from the } k\text{th vertex;} \\ -1 \text{ if the } j\text{th element is oriented toward the } k\text{th vertex; and} \end{cases}$$

e = the number of elements in the system.

The second set of equations, which involve the across variable (X), can be written for each circuit in the linear graph as

$$\sum_{j=1}^{e} b_j X_j = 0$$

where

$$b_j = \begin{cases} 0 \text{ if the } j\text{th element is not included in the } k\text{th circuit;} \\ 1 \text{ if the orientation of the } j\text{th element is the same as the orientation chosen for} \\ \quad \text{the } k\text{th circuit; and} \\ -1 \text{ if the orientation of the } j\text{th element is opposite to that of the } k\text{th circuit.} \end{cases}$$

This set of equations, together with the component terminal equations, constitutes the set of system equations. Theoretically it should be possible to solve the system equations to obtain the X and Y values for each component. In practice, the number of equations is so large that a number of shortcuts are required to reduce computer memory requirements. These shortcuts and a listing of the computer programs used to formulate and solve the system equations are given elsewhere (4).

APPLICATION OF THE MODEL TO NATIONAL FORESTS IN CALIFORNIA

This section describes the calibration and application of the systems model to simulate recreational travel to the national forests in California. Figure 4 shows the California national forests. The schematized regional transportation network is shown in Figure 5.

The components used in this test of the systems model are origin areas that represent counties, or groups of counties, and some out-of-state areas; 18 national forests in California; and the transportation network linking the origin areas with the national forests. The linear graph representation of the regional system is shown in Figure 6.

Input data to the model consisted of the origin flows computed by the macro-generation model (Table 4), the attraction indices of the national forests computed by the macro-attraction model (Table 3), and the travel time and flows associated with the 148 travel links representing the regional transportation system.

Calibration of the Systems Model

Calibration of the systems model involves estimation of the values of three parameters, K_1, K_2, and K_3 from Eqs. 5 and 7, that enable the model to duplicate best the observed travel pattern in the transportation network. Two levels of calibration were performed: coarse calibration runs followed by a set of fine calibration runs. The first calibration run involved the attraction constant, K_3. Four calibration runs were performed using values for K_3 of 0.001, 0.005, 0.01 and 0.05. From the patterns of the standard deviation of predictions obtained, K_3 was chosen at 0.005 with a coresponding standard error of prediction of 49.8 percent.

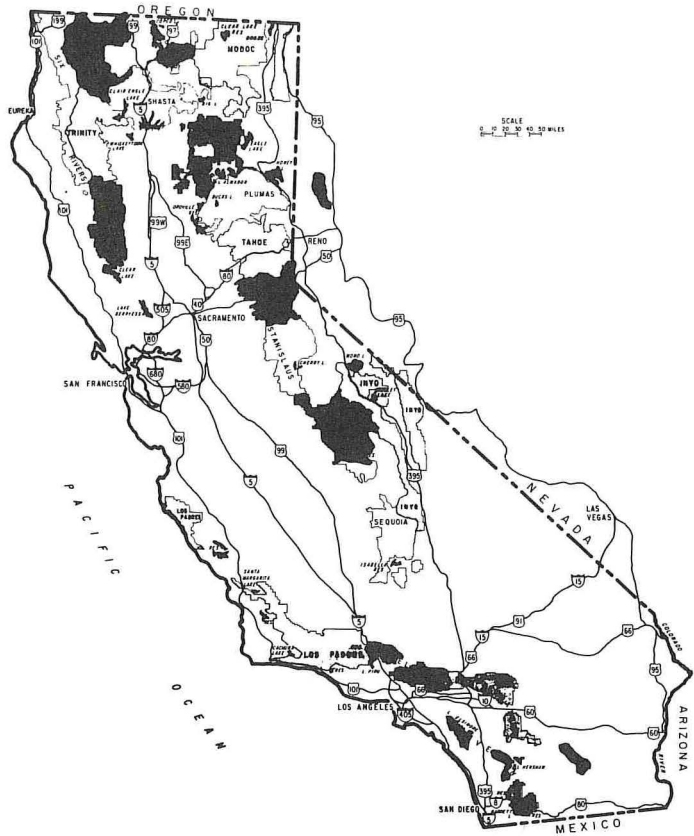Figure 4. National forests and regional transportation system in California.

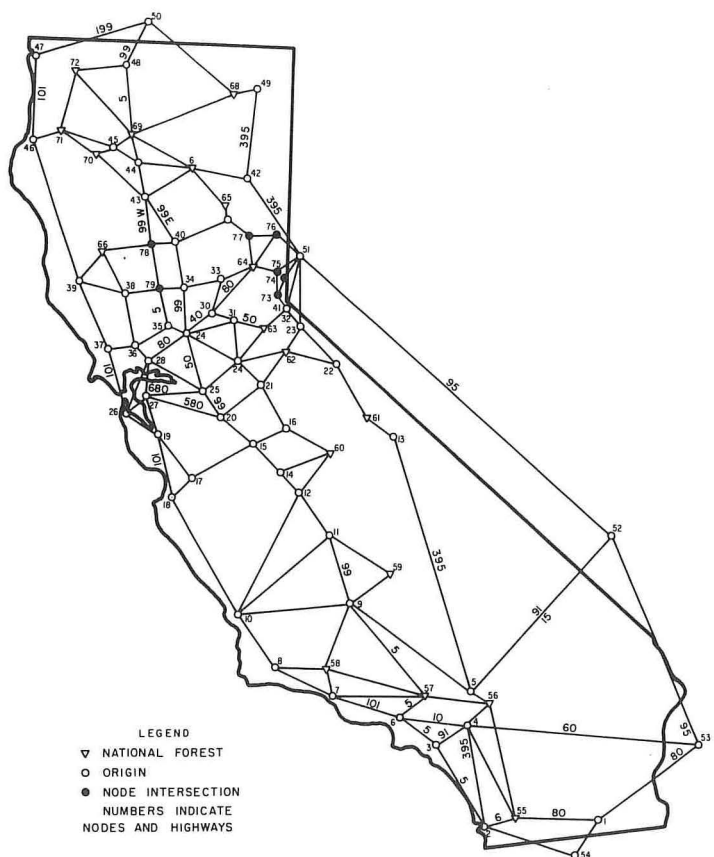Figure 5. Schematized regional transportation network in California.

LEGEND

▽ NATIONAL FOREST
○ ORIGIN
● NODE INTERSECTION
NUMBERS INDICATE
NODES AND HIGHWAYS

58

Figure 6. Linear graph
representation of the regional
transportation system.

REFERENCE POINT

LEGEND
—— BRANCHES
—— CHORDS

Table 4. Origin nodes with corresponding flows.

Origin Name	Flow (trips per year in thousands)		Origin Name	Flow (trips per year in thousands)	
	Day	Overnight		Day	Overnight
1. Imperial	168	160	26. San Mateo, San Francisco, Marin	912	1,000
2. San Diego	1,056	1,030	27. Alameda, Contra Costa	989	945
3. Orange	1,022	1,007	28. Solano	90	85
4. Riverside	342	368	29. Sacramento	903	915
5. San Bernardino	630	627	30. Placer	473	491
6. Los Angeles	5,725	5,705	31. El Dorado (Placerville)	163	182
7. Ventura	623	638	32. El Dorado (South Lake Tahoe)	142	168
8. Santa Barbara	650	672	33. Nevada	115	103
9. Kern	585	585	34. Sutter, Yuba	203	213
10. San Luis Obispo	310	325	35. Yolo	350	377
11. Tulare and Kings	2,463	2,603	36. Napa	159	144
12. Fresno	5,082	5,113	37. Sonoma	356	330
13. Inyo	877	919	38. Colusa, Lake	93	70
14. Madera	965	935	39. Mendocino	132	127
15. Merced	2,589	2,487	40. Butte, Glenn	256	261
16. Mariposa	430	488	41. Plumas	93	107
17. San Benito	113	103	42. Lassen	467	447
18. Monterey	567	656	43. Tehama	177	163
19. Santa Cruz, Santa Clara	611	605	44. Shasta	542	579
20. Stanislaus	927	917	45. Trinity	378	402
21. Tuolumne	113	103	46. Humboldt	582	560
22. Mono	464	488	47. Del Norte	164	186
23. Alpine	No information		48. Siskiyou	415	446
24. Calaveras, Amador	368	384	49. Modoc	158	182
25. San Joaquin	505	482			

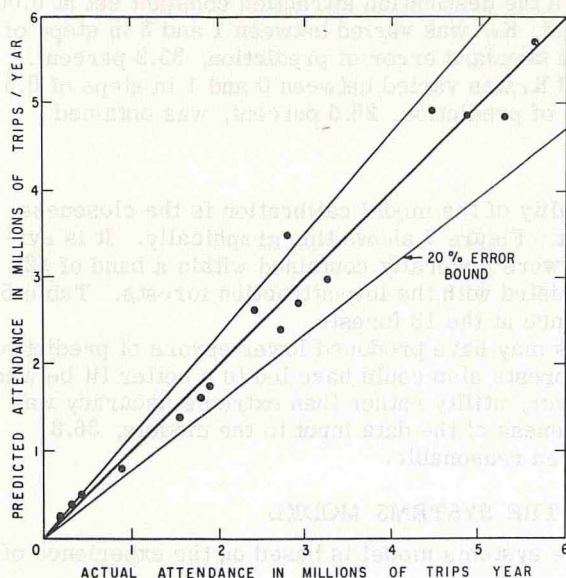Figure 7. Actual attendance versus predicted attendance.

Table 5. Comparison between actual and predicted attendance (trips per year).

Forest Name	Actual Attendance (in thousands)	Predicted Attendance (in thousands)	Percent Difference
"A"	5,633	6,253	+11.0
"B"	1,783	1,694	-5.0
"C"	2,693	2,570	-4.6
"D"	4,875	5,133	+5.3
"E"	424	461	+8.8
"F"	1,831	1,769	-3.4
"G"	2,945	2,833	-3.8
"H"	315	338	+7.3
"I"	236	246	+4.2
"J"	893	826	-7.5
"K"	5,289	4,802	-9.2
"L"	1,523	1,459	-4.2
"M" and "N"	3,273	3,178	-2.9
"O"	4,458	4,759	+6.7
"P"	236	251	+6.4
"Q"	2,411	2,554	+5.9
"R"	2,798	2,690	-3.9

The fine calibration involved trying different values of K_1 and K_2, the link resistance constant and exponent respectively. With the destination attraction constant set at 0.005 and K_1 at 0.1, the link resistance exponent, K_2, was varied between 1 and 3 in steps of 0.5. A value of K_2 of 3.0 gave the lowest standard error of prediction, 33.2 percent. Next K_2 was set at 3 and K_3 at 0.005, and K_1 was varied between 0 and 1 in steps of 0.5. At $K_1 = 0.5$, the smallest standard error of prediction, 26.8 percent, was obtained.

Discussion of Model Results

The criterion used to evaluate the quality of the model calibration is the closeness between model results and observed data. Figure 7 shows this graphically. It is evident that the errors in model prediction were generally contained within a band of ±20 percent. The largest errors were associated with the low-attraction forests. Table 5 gives the observed and predicted attendance at the 18 forests.

More adjustment of model parameters may have produced lower errors of prediction. Fine-tuning of the attraction indices of forests also could have led to a better fit between model results and observed data. However, utility rather than extreme accuracy was the goal here and, considering the coarseness of the data input to the models, 26.8 percent error of prediction was considered reasonable.

EVALUATION OF THE SYSTEMS MODEL

The following general evaluation of the systems model is based on the experience of performing these tests:

1. By far the biggest drawback of the systems model is the lack of sufficient quantities of the right type of data. This applies particularly to the inventory of the natural resources, activities, facilities, and services in the forest.

2. The systems model is both simple and realistic in its treatment of component formulations and interactions. The results clearly demonstrate its realism. A look at the mathematics (4) will leave no impression of simplicity. However, once the model has been constructed and programmed, its use requires only the input of origin, travel link, and destination data cards.

3. The systems model performed adequately on very coarse and scant data. This situation cannot be generalized, however. The success achieved might be due to the relatively simple relationships that exist under low-density traffic conditions. For more complex traffic patterns, much more detailed data would be required than were used in this study. This is true of any allocation model.

4. The amount of personal judgment is identified and controlled. A certain amount of personal judgment was employed in quantifying the link resistance factors and the attraction indices. Judgment and intuition are absent once the input data are fed into the model and the consequences of an alternative plan are being estimated.

5. The systems model makes good use of specialist's time. Once the systems model is programmed it can be applied by anybody who can code a transportation network. The mathematics in the model need not be understood by the operator. However, the interpretation and further application of the model's output requires a specialist.

6. The model permits easy upgrading of its formulation and updating of its predictions. By modeling each component separately in terms of its physical characteristics, the systems model makes allowances for easy remodeling of the components as more knowledge is gained. Because of its running speed, the systems model facilitates sensitivity analyses.

CONCLUSION

As a result of the work described in this paper it can be concluded that the systems model is effective in simulating the California forest recreation system and in describing the flow of recreational traffic to the various national forests. The macro-generation and macro-attraction models, which provide inputs to the systems model, also perform their function satisfactorily.

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THE ROLE OF NETWORK ANALYSIS TECHNIQUES IN RESOURCE MANAGEMENT PLANNING

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Planning for resource development and management considers the accessibility provided by a transportation network. Two applications of network analysis techniques for resource planning in national forests are described—transportation for timber activity and administrative travel in national forests. The access to timber and the haul costs on transportation facilities influence the timber resource development pattern. A minimum-path algorithm is adapted to provide several measures of the effectiveness of a transportation system in servicing possible timber sales, available mills, and available markets. Use of this procedure in evaluating alternative timber resource development plans is described. The administration of national forest activities requires periodic inspection and servicing of activities. A technique for finding the optimal routing of administrative travel is investigated. The method is based on a modified branch-and-bound technique used in solving discrete programming problems.

•THE MANY types of travel in national forests can be classed into two broad categories: recreational travel and nonrecreational travel. Procedures developed by this study to analyze recreational travel are discussed elsewhere (2, 3). Procedures to analyze nonrecreational travel are discussed here. Nonrecreational travel in national forests is associated with many diverse activities. Techniques to analyze travel for two of the most important of these activities are presented in this paper. These techniques are a timber transport model and an administrative travel model.

Both of these are network analysis models. They are used in this situation, in preference to demand models, for a number of reasons. First, because both types of travel are characterized by low daily traffic volumes, demand models would be affected adversely by the high variability encountered in analyzing and estimating small quantities. Second, because timber transport travel patterns are quite irregular over a day, and even over a season, it would be difficult to find an appropriate theory on which to base an associated demand model. Third, the route of interest may be based on different criteria for different applications. For example, timber transport analysis is most often based on minimum transport cost, fire attack travel on minimum travel time, and campground service on either. The use of demand models to perform the analyses would tend to obscure this important underlying issue.

TIMBER TRANSPORT COST ANALYSIS TECHNIQUE

Definition of Problem

Timber harvesting is a major activity in national forests. Under a timber harvest program, the timber in designated areas is sold by bid to logging contractors when the trees within the area have reached maturity or have been damaged by insects, fire, or blight.

Many road investments in national forests are prompted by the need to provide accessibility to these timber harvest areas. One principal consideration in selecting road construction or improvement projects is the relative timber transport cost associated with each alternative project. To a lesser extent the designation of the harvest areas themselves is influenced by these same costs.

Consequently, a method was developed to determine the minimum-cost routes for transporting timber through a forest transportation network (4). Here "transport cost" is interpreted in its most general sense and may correspond to either travel cost, travel time, or travel distance. These minimum costs indicate the effectiveness of proposed transportation systems in serving traffic generated by timber-cutting activities. The technique that computes the minimum haul cost routes associated with a given road network-harvest area combination is called the "timber transport model."

This problem differs from other minimum-path problems in that the transport of timber products to market is done in two stages. Logs are cut, trimmed, and loaded at the timber harvest areas, called "timber sales." They are then hauled to mills for processing into lumber. These mills may be located within the forest area or at some distance from the forest. After processing, the finished lumber is then hauled to the markets, which may be railheads, ports, or urban areas. Both legs of the trip from sale to market are included in this analysis of the problem.

Description of Technique

The timber transport model determines the minimum travel path through a transportation network for a timber sale-mill-market combination by minimizing either travel cost, travel time, or travel distance. The choice of the criterion to be minimized is made by the analyst. To aid in the evaluation of the selected routes, the values of the other impedance measures are also determined; for example, the travel time and travel distance are also calculated over each minimum travel cost path.

A digital representation of the forest road network must be prepared. Nodes representing the locations of timber sales, mills, and markets must be included therein. A "link" is used to represent a section of roadway that is homogeneous with respect to road class and geometrics. Each link is characterized by its road class, length, and either travel time or average link speed. If the characteristics of a section of road change significantly, that section of road would be represented by more than one link, since, due to the effects of grade and geometrics, link characteristics may be quite different for opposing directions of travel.

The program can accept the network data on either cards or magnetic tape. An optional routine in the program will generate a magnetic tape in the appropriate format. Another routine is available that will update and edit the network data on tape. The network representation provided by the network data management system, developed under this study, satisfies the data requirements for both recreational and nonrecreational models. However, a simpler network representation can be used to analyze timber— that is, one with some travel time and travel cost data omitted.

Timber haul cost functions that reflect transport cost characteristics on forest roads have been defined by the U. S. Forest Service (Fig. 1). Each haul cost function is represented by three linear segments, with the marginal cost α_1 (in dollars per truck-mile) applying at any point within the first distance increment, α_2 within the second, and α_3 within the third. Since cost characteristics differ for log and lumber transport, separate haul cost functions have been developed for each. These unit cost functions also vary by class of road, forest roads varying in character from single-lane dirt roads to high-standard highways. The model can accept up to 10 haul cost functions for both log and lumber transport.

The output of the program identifies the least transport cost route for every sale. Included in each route are a least-cost mill and market to which each timber sale has been assigned by this program. The values of the three impedance measures over the best route are also output. A recent modification to the program provides a summary of the number

Figure 1. The general haul cost function.

TOTAL HAUL COST

CUMULATIVE DISTANCE OF HAUL
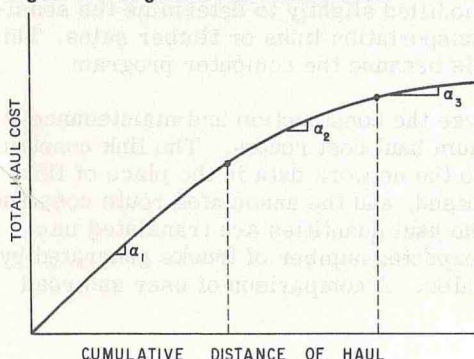
of times each link of the network is used in the minimum-cost paths for all the timber sales analyzed and the volume of timber carried by each.

Logic

The timber transport model uses a shortest-path algorithm developed by the Road Research Laboratory in Great Britain (6). This is an outgrowth of the Moore algorithm developed by the U. S. Bureau of Public Roads. The algorithm is of the tree-building type wherein the minimum path is found from a specified origin to all destinations. However, once a satisfactory destination is reached, the algorithm stops; hence, a complete tree is not built. This algorithm was chosen both because it is very efficient and also because it accommodates a simple and easily understood network representation. This is desirable because many of the users of this technique will have only limited knowledge of network theory.

The minimum-path algorithm is first applied with each mill serving as an origin in turn and with the markets serving as destinations. The algorithm searches until the closest market to each mill is identified. These pairings of mills with markets and the transport costs between every pair are saved. More than one mill may be tied to a single market.

The model then applies the minimum-path algorithm to each timber sale as an origin in turn, with the mills as destinations. As each mill is reached, the incremental transport cost from the mill to its "tied" market is added and the total transport cost for that sale-mill-market combination is compared to the previous minimum. The lesser cost combination of the two is saved. The algorithm continues until the minimum cost paths to all mills, and to their tied markets, have been considered. In this way, the model determines the least cost sale-mill-market routing for all timber sales under consideration.

Applications

This technique was the first analytical model developed by the study. The primary objective was to provide an efficient procedure for evaluating the timber haul costs for timber sales, which this method does. However, the possible applications of this technique go beyond that originally intended.

The timber transport model is useful for planning future transportation networks. Forest management plans must provide direction for the future timber harvest program, indicating the locations, approximate quantities of timber, and scheduling of possible timber sales as well as specification of a future transportation network. The model can be employed to investigate the efficiency of various transportation network alternatives for serving the timber travel generated by the proposed harvest plans. The total transport costs are determined for each alternative network by summing the products of the expected number of trucks generated by the timber sales and the route haul cost rates per truckload for all timber sales. The differences in these total costs indicate the relative efficiency of the various network alternatives for a particular timber harvest plan.

The technique can assist the analyst and/or decision-maker in his search for efficient alternatives. The existing alternatives can be modified slightly to determine the sensitivity of transport costs to changes in certain transportation links or timber sales. This technique is very effective for sensitivity analysis because the computer program execution is extremely fast.

In addition, the technique can be used to analyze the construction and maintenance costs associated with hauling timber over minimum haul cost routes. The link construction costs and maintenance costs are entered into the network data in the place of link travel times. The minimum-cost path is determined, and the associated route construction and maintenance costs are accumulated. The haul quantities are translated into estimates of total user costs by multiplying the expected number of trucks generated by every timber sale by the appropriate haul cost rates. A comparison of user and road costs can then be made.

THE ADMINISTRATIVE TRAVEL MODEL

Definition of Problem

There are several types of regularly scheduled administrative travel in national forests. These include trips to service campgrounds, to patrol areas for fire prevention, and to inspect logging activities. The origins and destinations of these trips are usually clearly defined, although the routes that are used may vary.

Administrative travel does not generate a high volume of traffic. However, significant benefits can accrue to the Forest Service, and therefore to the public, if the optimal routing to perform these tasks is determined. The reduction of costs for travel and the equitable use of available personnel through improved scheduling can significantly improve administrative efficiency. A major portion of national forest administrative travel is associated with campground service. Because of the importance of campground service routing and because it is representative of other administrative travel problems, the administrative travel model is presented in terms of its application to this activity.

In many national forests, campground service is performed by personnel of the ranger district that contains the campground. Therefore, the problem reduces to the analysis of travel on the transportation network of the ranger district. Daily campground service travel often begins at the district ranger station, and service personnel return to the station by day's end. Consequently, the origin of travel is the ranger station, and the destinations are the campgrounds and, at day's end, the ranger station.

Techniques have been developed to handle problems that are quite similar to that posed here. One of these is the "traveling salesman problem." That formulation can be solved in many ways with the aid of special linear programming and dynamic programming techniques (7, 8). However, there are two major differences between the problem posed here and the traveling salesman problem:

1. All trips begin and end at the ranger station every day of the service period, and
2. A location, in this case a campground, can be visited more than once within a service period, though it is only serviced once.

Because of these differences, this problem cannot be solved by a traveling salesman algorithm. On the other hand, there does exist an integer programming algorithm that is useful for solving this special class of discrete programming problems (9, 10). This algorithm employs a modified branch-and-bound technique. When the problem is properly formulated, this algorithm can be used to solve the optimal routing problem for campground service.

Formal Problem Statement

The problem is to determine the optimal route to service all campgrounds in a ranger district within a certain number of days. The number of days required depends on the number and sizes of campgrounds and the size and layout of the ranger district. The base of operations is the ranger station. A number of assumptions are made:

1. Each daily trip begins and ends at the ranger station; no overnight stays in the forest are permitted.
2. The minimum travel times between every pair of nodes are known.
3. A campground node can be visited more than once but only serviced once.
4. One team is assigned to perform the service for all campgrounds. If a ranger district actually has more than one team, the problem formulation can be modified accordingly.

Formulation of the Problem

The formulation of an example problem demonstrates the technique (5). The transportation system is shown in Figure 2. The ranger satation is represented by RS and campgrounds by C's. The nodes of the transportation network are numbered.

Dummy links are added to the network in the formulation of the problem. The schematic network is shown in Figure 3. A two-way dummy link is added on each camp-
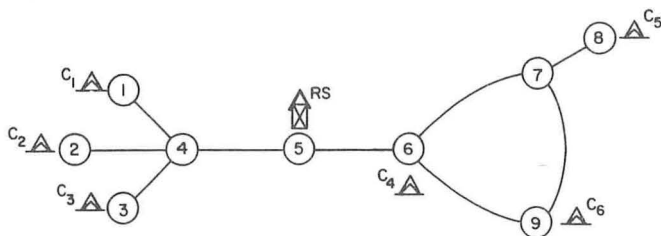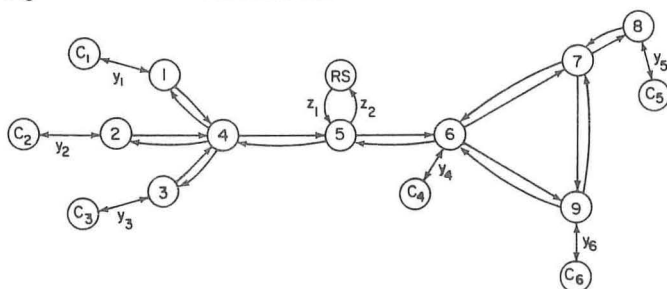
Figure 2. Forest road network.

Figure 3. Schematic road network.

ground and two one-way dummy links are introduced for the ranger station. On the schematic diagram, y's are two-way dummy links and z's are one-way dummy links.

The objective function is to minimize the total travel cost

$$\text{Min } Z = \sum_{k=1}^{H} \sum_{\{(i,j)\}} c_{ij} \, x_{ijk} \qquad (1)$$

where

$\{(i, j)\}$ means the set of all N links in the transportation network—each (i, j) represents an ordered pair of nodes connected by a one-way link,

Z = total travel cost,

c_{ij} = travel cost on the one-way link from node i to node j,

x_{ijk} = 1 if a trip is made on line (i, j) on day k,
       = 0 if not,

N = the total number of links in the transportation network, and

H = the number of 8-hour working days needed in the service period,

subject to the following constraints:

1. Travel time to and between campgrounds plus the aggregate service time must be less than or equal to 8 hours in any one day; i.e.,

$$\sum_{\{(i,j)\}} t_{ij} x_{ijk} + \sum_{s=1}^{M} m_s y_{sk} \leq 8 \text{ (hours), for } k = 1, 2, \ldots, H \qquad (2)$$

where

t_{ij} = travel time on the one-way link from node i to node j,

m_s = time to service campground s,

y_{sk} = 1 if a campground is serviced on day k,

   = 0 if not, and

M = number of campgrounds.

2. Each campground cannot be serviced more than once within the service period; i.e.,

$$\sum_{k=1}^{H} y_{sk} \leqq 1, \text{ for } s = 1, 2, \ldots, M \tag{3}$$

3. Each campground is serviced at least once during the service period; i.e.,

$$-\sum_{s=1}^{M} \sum_{k=1}^{H} y_{sk} \leqq -M \tag{4}$$

4. Each day at least one service trip originates from and returns to the ranger station; i.e.,

$$-\sum_{k=1}^{H} (z_{1k} + z_{2k}) \leqq -2H \tag{5}$$

where

z_{1k} = 1 if a service trip originates at the ranger station,

   = 0 if not, and

z_{2k} = 1 if a service trip returns to the ranger station,

   = 0 if not.

5. For each campground serviced on day k, there must exist at least one round trip routing to and from the ranger station; i.e., for campground 1,

$$y_{1k} - P_{1k1} = 0 \tag{6}$$

$$2P_{1k1} - x_{41k} - x_{54k} \leq 0 \tag{7}$$

$$y_{1k} - R_{1k1} = 0 \tag{8}$$

$$2R_{1k1} - x_{14k} - x_{45k} \leq 0 \tag{9}$$

For campground 2,

$$y_{2k} - P_{2k1} = 0 \tag{10}$$

$$2P_{2k1} - x_{42k} - x_{54k} \leq 0 \tag{11}$$

$$Y_{2k} - R_{2k1} = 0 \tag{12}$$

$$2R_{2k1} - x_{24k} - x_{45k} \leq 0 \tag{13}$$

For campground 3,

$$y_{3k} - P_{3k1} = 0 \tag{14}$$

$$2P_{3k1} - x_{43k} - x_{54k} \leq 0 \tag{15}$$

$$y_{3k} - R_{3k1} = 0 \tag{16}$$

$$2R_{3k1} - x_{34k} - x_{45k} \leq 0 \tag{17}$$

For campground 4,

$$y_{4k} - P_{4k1} = 0 \tag{18}$$

$$P_{4k1} - x_{56k} \leq 0 \tag{19}$$

$$y_{4k} - R_{4k1} = 0 \tag{20}$$

$$R_{4k1} - x_{65k} \leq 0 \tag{21}$$

For campground 5,

$$y_{5k} - P_{5k1} - P_{5k2} = 0 \tag{22}$$

$$3P_{5k1} - x_{78k} - x_{67k} - x_{56}k \leq 0 \tag{23}$$

$$4P_{5k2} - x_{78k} - x_{97k} - x_{69k} - x_{56k} \leq 0 \tag{24}$$

$$y_{5k} - R_{5k1} - R_{5k2} = 0 \tag{25}$$

$$3R_{5k1} - x_{87k} - x_{76k} - x_{65k} \leq 0 \tag{26}$$

$$4R_{5k2} - x_{87k} - x_{79k} - x_{96k} - x_{65k} \leq 0 \tag{27}$$

And for campground 6,

$$y_{6k} - P_{6k1} - P_{6k2} = 0 \tag{28}$$

$$2P_{6k1} - x_{69k} - x_{56k} \leq 0 \tag{29}$$

$$3P_{6k2} - x_{79k} - x_{67k} - x_{56k} \leq 0 \tag{30}$$

$$y_{6k} - R_{6k1} - R_{6k2} = 0 \tag{31}$$

$$2R_{6k1} - x_{96k} - x_{65k} \leq 0 \tag{32}$$

$$3R_{6k2} - x_{97k} - x_{76k} - x_{65k} \leq 0 \tag{33}$$

where

$P_{sk\ell}$ = 1 if route ℓ is used to travel from the ranger station to campground s on day k,
= 0 if not, and
$R_{sk\ell}$ = 1 if route ℓ is used to return from campground s to the ranger station on day k,
= 0 if not.

The Branch-and-Bound Technique

Branch-and-bound algorithms have been studied extensively since 1960 as a technique to solve special types of integer linear programming problems (8). The branch-and-bound technique can be applied to the campground service problem as previously formulated. The technique begins by solving the problem, using the simplex method, without integer constraints to get an initial value of the objective function Z_0. If the values of all variables are integer, then the solution of the problem has been found. If they are not, one noninteger variable is set equal to zero and the problem is solved again, giving Z_1. The same variable is then set equal to one and the problem is solved for a third time, giving Z_2. If the objective function is to be minimized, the setting of the noninteger variable that yields the minimum of Z_1 and Z_2 is retained, establishing a "terminal node" $\overline{Z}_1$. If

all variables now have integer values, the final solution has been found. If some do not, the algorithm "branches" on $\overline{Z}_1$ and sets some other noninteger variable equal to zero. The problem is again solved to get a value of Z_3 for the objective function. The same variable is then set equal to one, and the problem is solved to give Z_4. If for both solutions all variables have integer values, the solution yielding the minimum of Z_3 and Z_4 is the final solution of the problem. If only one solution has all integer variables, it is the final solution. If neither solution does, the algorithm branches on a new terminal node, $\overline{Z}_2$, which is the minimum of Z_3, Z_4, and the maximum of (Z_1, Z_2). The technique continues in this manner until a solution is found that has all integer-valued variables and a value of the objective function less than or equal to any other terminal node.

A major consideration is the amount of computer time required to perform this analysis. At each step a linear program must be solved using the simplex algorithm, and hence the computational time would be very large for large networks. Fortunately the road networks in ranger districts are usually not extensive. Also, as implied in the example problem formulation, no nodes should be defined between intersections. All links between intersections should be aggregated and formulated in the problem as one link. The number of constraints is reduced by two for every node that is eliminated between intersections. The amount of time required to solve the problem using the simplex algorithm increases with an increase in the size of network because the number of link variables increases. Further, the computation time and storage requirements are increased because the number of terminal nodes to be investigated and saved also increases with the number of link variables.

Discussion of the Technique

As seen in the problem formulation, the specification of the constraint equations for network flows could be a formidable task for a large network. However, this tedium can be eliminated by a computer program. Such a program would take coded network data as input and generate network flow constraint equations. The other constraint equations need only be modified when there are changes in the frequency of campground service, in the number of service teams, or in other factors requiring a change in the basic problem formulation. Otherwise, the only inputs required for the model, other than network data, are the number of days in the service period and the number and service times of campgrounds.

Some situations require a modification of the problem formulation. For example, some campgrounds may have to be serviced more than once during the service period. The constraints imposed by Eqs. 3 and 4 limit the service to once and only once during the service period. If, for example, campground number 5, due to its size and heavy use, needs to be serviced twice during the service period, these constraints are modified as follows:

1. Each campground, except number 5, cannot be serviced more than once within the service period:

$$\sum_{k=1}^{H} y_{sk} \leqq 1, \quad s = 1, \ldots, 4, 6, \ldots, M \tag{3.1}$$

2. Campground 5 cannot be serviced more than once within the first service subperiod:

$$\sum_{k=1}^{H_1} y_{5k} \leqq 1 \tag{3.2}$$

where $H_1 = \sim H/2$ (first subperiod).

3. Campground 5 cannot be serviced more than once within the second service subperiod:

$$\sum_{k=H_1+1}^{H} y_{5k} \leqq 1 \tag{3.3}$$

4. The number of times campgrounds are serviced during the entire service period is the number of campgrounds plus one additional service activity:

$$-\sum_{s=1}^{M} \sum_{k=1}^{H} y_{sk} \leqq -(M + 1) \tag{4.1}$$

A desired lag between service times at campground 5 can be introduced into the campground servicing schedule by rearranging the schedules for entire days within the service period. Moving entire days around does not affect the optimality of the solution.

The number of days in the service period, H, must be specified by the analyst or administrator in the area, based on his estimate of the number of 8-hour days that the service team would need to service the campgrounds. If H is specified too small, no feasible solution to the problem will be found. If H is specified too large, an optimal solution will be found in which all the x and y variables have zero values for the extra days.

Applications

The administrative travel model has application for determining the optimal routes to service campgrounds, to patrol for fire prevention, to inspect logging activities, and to perform other administrative activities requiring regular travel to fixed destinations. Thus, the technique can be used extensively by administrators to reduce costs of travel and to schedule manpower efficiently.

The technique can be used in planning to determine the relative efficiencies of alternative networks. For any proposed resource management plan, which includes a proposed network, the model computes the minimum achievable administrative travel costs. These can be compared to the corresponding travel costs for other proposed plans to determine their relative efficiency in serving administrative travel.

By expanding the problem formulation to cover an entire national forest, the distribution of campground service responsibility and locations of ranger district boundaries can be evaluated. All ranger stations would be treated as origins, with each having a service team. In this revised formulation, each campground can be serviced by any service team. Where the total travel service costs are reduced by rearranging service responsibilities, the actual or functional ranger district boundaries could be revised.

CONCLUSION

Network analysis techniques are useful tools for resource management planning. They have the ability to analyze the efficiency of proposed transportation networks and are especially suited to the analysis of nonrecreational travel.

Two techniques have been presented in this paper. The timber transport model employs a minimum-path algorithm to generate the least travel cost route to the most economical mill and market for each timber sale. The administrative travel model uses a modified branch-and-bound technique to analyze the efficiency of a transportation network in serving administrative travel. These two models are the first of a set of techniques still being developed to aid forest planners in analyzing nonrecreational travel.

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